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On the Problem of the Existence of Mesotrons in Auger Showers

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A discussion is given of the different possibilities which would lead to the assumption of the presence of mesotrons in extensive atmospheric showers, or the so-called Auger showers. The difficulties involved in the problem of the experimental evidence for the existence of these mesotrons are shown to be, in general, considerable. Three kinds of experiments are described in which mesotrons associated simultaneously with other particles are found. These particles are present even at large distances ($\sim$20 meters) from the observed mesotrons. However, they are much more infrequent than the particles which are found in the Auger showers, investigated under conditions similar to those of the present experiments. Qualitatively, the observed phenomena could be due, not to mesotrons associated with an Auger shower, but to single mesotrons accompanied by collision electrons which are projected by these mesotrons along their path in the air. There exists, however, a definite quantitative disagreement between the observed values and the theoretical values which are calculated for the considered collision processes. Therefore, at least part of the observed mesotrons could actually belong to an Auger shower. But, on the other hand, explanations are formulated which might, at least partly, account for the mentioned quantitative disagreement. Thus, only after these explanations are tested by experiment will it be possible to decide more definitely as to the presence of mesotrons in Auger showers.

PRELIMINARY CONSIDERATIONS

THE problem of the presence of mesotrons in extensive atmospheric cosmic-ray showers, or Auger showers (here referred to as A showers) has been investigated since the first experiments were carried out on these showers.[1] The particular interest of this problem arises from its possible relation to different phenomena, which are mainly: (a) the development of a cascade shower originating from a particle of very high energy, up to 10^{16} ev, and (b) the mechanism itself of the generation of mesotrons in cosmic rays.

We shall briefly examine here the different possibilities which would lead to the assumption of the presence of mesotrons in A showers, and then discuss the problem of their experimental evidence.

An analogous discussion can be applied, in part, for heavy penetrating particles, other than mesotrons, which might also be present in A showers.

A. Showers Originating from Primary Soft Particles

In case the primary soft particles (electron or photon) multiply only by processes described in the theory of cascade showers and if one admits that the cascade theory is valid for particles having energies up to 10^{16} ev, then one should not expect to find mesotrons in A showers since

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[1] P. Auger, R. Maze, and T. Grivet-Meyer, Comptes rendus **206**, 1721 (1938); W. Kolhörster, J. Matthes, and E. Weber, Naturwiss. **26**, 576 (1938); P. Auger, P. Ehrenfest, R. Maze, J. Daudin, Robley, and A. Freon, Rev. Mod. Phys. **11**, 288 (1939); H. Euler and H. Wergeland, Naturwiss. **27**, 484 (1939); N. Hilberry, Phys. Rev. **60**, 1 (1941).

this theory does not predict at all any creation of mesotrons in the multiplication process leading to the building up of the shower.

B. Showers Originating Indirectly from High Energy Mesotrons

An *A* shower can originate from a mesotron by a close collision process with an electron,[2,3] by a bremsstrahlung process providing a high energy photon,[3] or possibly by a decay of a short life mesotron of very high energy. The main difference between cases A and B is that the high energy parent particle of the *A* shower is a secondary instead of being a primary. In the present case, however, the *A* shower starts at any altitude in the atmosphere wherever the high energy secondary particle is created, and not at the top of the atmosphere, as in the case of the primary parent particle. We will leave aside the question of how far the origin of the *A* showers could be attributed to such mechanisms since our intention is to limit the present discussion only to the problem of the presence of mesotrons in *A* showers.

It is expedient to remark here that in order to obtain a widespread shower, the energy transfer from the mesotron to the high energy soft particle should have taken place in the upper atmosphere, otherwise only a burst of particles of a small extension could be observed. In any case, the probability of detecting in the whole shower the only present mesotron—which is the source of that shower and is assumed to have lost only part of its energy in the above-described processes—will be very small. On the other hand, the probability of detection of this mesotron should decrease at least in proportion to the frequency of its occurrence in the differential energy spectrum of the mesotron radiation.

C. Secondary Production of Mesotrons

1. The problem of detecting mesotrons in the *A* showers would look less hopeless if there should be a creation of a larger number of mesotrons within these showers. In case the created mesotrons are of high energy, they must have originated in the core of the *A* shower. They will travel together with the high energy particles of the central part (core) of that shower and remain close to its axis.

In order to detect these mesotrons one will have to eliminate from the core of the *A* shower the soft high energy particles which are mixed together with the mesotrons.

2. From the experimental point of view, the identification of the high energy mesotrons in the core of the *A* shower will present great difficulties. Indeed, *in counter experiments*, the only reliable criterion for the identification of the mesotron is its small probability of creating a shower after having traversed a larger number of radiation units of any material. Generally, it is sufficient to place below this material a group of counters, the function of which is to distinguish between a single particle or a shower emerging below the material. If, however, there are present many mesotrons of high energy, they could discharge this group of counters and would act then in the same way as a cascade shower. The above criterion will fail in this case. It will therefore be necessary to increase still more the thickness of material in order to eliminate eventually the less energetic mesotrons until one single mesotron remains. Such a procedure could lead to the use of prohibitively large thicknesses of absorbing material. However, if one could rely on the strict validity of the cascade theory for extremely high energies (10^{13}–10^{16} ev) of the soft particles which are involved in the *A* showers, then all particles, whatever their number might be, emerging below, for example, a lead absorber of a thickness of, say, $\frac{1}{2}$ meter, should consist of penetrating particles (mesotrons), or at any rate of particles originating from a penetrating particle. This follows from the fact that any soft particle of an *A* shower of energy up to 10^{16} ev should be stopped in the indicated lead absorber since the cascade theory shows that for high energy soft particles the average cross section for the pair production and the fractional energy loss by radiation processes are practically independent of the energy of these particles and are, for one radiation unit of length of any material (0.5 cm for Pb), equal to ~ 1. In any case, there will always be a possibility that the mesotrons finally identified were, originally, not present at all in the *A* shower, but were created in the

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[2] H. J. Bhabha, Proc. Roy. Soc. **164**, 257 (1938).

[3] R. F. Christy and S. Kusaka, Phys. Rev. **405**, 411 (1941).

absorber—for example, a lead absorber—where the cross section for such a process might be very different from that in air. Therefore, it would be best to use, as absorbers, materials having about the same atomic number as air, e.g., water. Such experiments could be carried out by immersing the detecting apparatus in a lake.

3. In cases where one could demonstrate that the particles emerging below the thick absorber did not belong primarily to a dense part of an *A* shower, in other words, if one could prove that the density of particles which are then present *above* the absorber is relatively low, the particles below the absorber could be attributed to a mesotron with a considerably higher probability than in the previous case. Indeed, in the present case, the particles below the absorber could not have originated from a high energy electron or photon, since such particles would almost always be accompanied either by other particles of the core of the *A* shower, or by a cascade shower originated along their path in air, or even more frequently by both. It is evident that these cases in which the mesotrons are present in the low density region (wing) of the *A* shower are the most favorable ones for their detection. However, as will be seen more in detail in the experimental part of this paper, the question may then arise whether the observed mesotrons belong actually to an *A* shower or whether they can be considered as single mesotrons ejecting electrons along their path in air by collision processes.

4. Finally, it should be pointed out that in case the mesotrons created within the core of the *A* showers are of low energy, of the order of magnitude of their rest mass energy, the probability of their detection would again be small since they would very likely be stopped in an absorber of a thickness smaller than required to filter out all the high energy soft particles present in the core. They would naturally be stopped already in the air, in case they are created high in the atmosphere.

D. Delayed Particles in *A* Showers

As a direct consequence of the possible presence of low energy mesotrons in an *A* shower there should exist a certain number of electrons, resulting from the decay of the mesotrons, and occurring with delays—of the order of magnitude of the mean lifetime ($\sim 2\times 10^{-6}$ sec.) of the mesotron—with respect to all other particles in the same parent *A* shower. Inversely, a demonstration of the existence of such delayed particles in an *A* shower would provide probably the best evidence of the presence of mesotrons in *A* showers. For that purpose, an apparatus was built which makes it possible to measure delays occurring between a group of counters selecting *A* showers and another counter placed in the neighborhood of this group of counters. This outfit records only those delays which occur within $\sim 10\times 10^{-6}$ sec. A more detailed account of this method will be given at a later date.

EXPERIMENTS

Several types of counter-tube experiments were performed in order to obtain direct evidence of the possible presence of mesotrons in *A* showers. These investigations were carried out at sea level (Chicago, altitude 610 feet) and at a higher altitude[4] (Echo Lake, Colorado, altitude 10,618 feet). In all experiments here described the master group method was used. The general principle of this method was described in a previous paper,[5] to which we shall refer here as I. All counters used in the present experiments are filled with a mixture of argon and alcohol.[6] They have an effective area of $5\times 50=250$ cm^2 and operate at 1200 volts. The resolving time of the coincidence circuits is about 2×10^{-6} sec. for a separation between counters less than 2 meters and about 4×10^{-6} sec. for a separation of 22 meters.

Throughout this paper, any counter which does not belong to the master group will be called an analyzing or distant counter. When speaking about discharges or counting rates in such a counter, it should be understood, unless specified otherwise, that the master group was simultaneously discharged.

The discharges of the analyzing counters were recorded on a photographic film by means of neon lamp flashes. The photographic recorder was of a type similar to that used by Schein,

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[4] During the Mount Evans Expedition of the University of Chicago in August-September, 1943.

[5] A. Rogozinski, Phys. Rev. **65**, 207 (1944).

[6] These counter tubes were designed by Dr. V. H. Regener.

Jesse, and Wollan[7] in their stratosphere experiments.

Experiment I

In the first experiment,[8] which was carried out at sea level and was of a preliminary character,

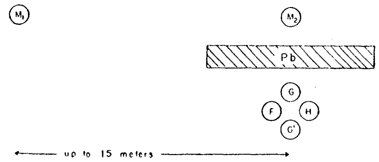

FIG. 1. Counter arrangement in Experiment I.

the master group consisted of two counters M_1 and M_2 connected in twofold coincidence and separated by a horizontal distance up to 15 meters. The role of this master group was to select A showers (Fig. 1). A set of 4 analyzing counters F, G, G', H, placed below M_2 could be separated from that counter by lead absorbers up to 12.5 cm of thickness. The counters M_2, F, G, G', and H were located inside a Celotex box which was placed in open air and could be heated. The counter M_1 was placed indoors below a thin tile roof.

It was found, for different thicknesses of the lead absorber, that a certain fraction of the fourfold coincidences M_1M_2GG' was not accompanied by a discharge in any of the counters F and H. Therefore, it is assumed that these events could be attributed to single non-shower producing particles present in that part of the A shower which strikes the lead absorber. These particles which emerge below a lead thickness of several radiation units without producing an abundant shower should be heavy particles of the penetrating type, such as mesotrons.

Experiment II

1. In order to determine the density of particles in the region of the shower in which the penetrating particle is located, experiments were performed (at Echo Lake) with the same counter arrangement as described in I. In this experiment the master group consisted of two counters M_1 and M_2 connected in twofold coincidence and placed one above the other. In order to increase the counting rate, two counters connected in parallel were used for M_1 and for M_2 (Fig. 2). At a horizontal distance of 22 meters from the master group there was placed the set of seven analyzing counters K_1, K_2, K_3, F, G, G', H, of which the upper set of counters, K_1, K_2, K_3, could be separated from the lower set, F, G, G', H, by variable thicknesses of a lead absorber. The four counters of the master group were put outdoors in a small wooden box which had a wall thickness of $\frac{1}{2}$ in. and which could be heated. The set of analyzing counters was located indoors under a thin wooden roof.

2. The results obtained in Experiment II dealing with those cases where a shower emerges below a lead absorber (coincidences $M_1M_2FGG'H$) were already described in I. Here we shall investigate in detail such events, which could be attributed to penetrating particles, like mesotrons, emerging below the lead absorber without being accompanied by a shower. These events are recorded as coincidences M_1M_2GG', which are not accompanied simultaneously by a discharge in any of the counters F and H. Such an "anticoincidence" will be represented by the symbol $M_1M_2GG'-FH$.

The results of these experiments are summarized in Table I. However, for comparison with those cases in which a shower emerges below the lead absorber, the corresponding data are also given in this table. The first column of Table I gives the total time of recording for a certain thickness of lead, which is indicated in column II. The columns from III to XI represent average counting rates, expressed in number of coincidences per 10 hours. Column III gives the frequencies of the anticoincidences $M_1M_2GG'-FH$ or the coincidences $M_1M_2FGG'H$, regardless of discharges which might have occurred simultaneously in the upper set of counters K_1, K_2, K_3. Columns IV to X give the frequencies of those events $M_1M_2GG'-FH$ or

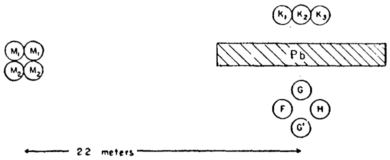

FIG. 2. Counter arrangement in Experiment II.

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[7] M. Schein, W. P. Jesse, and E. O. Wollan, Phys. Rev. **59**, 615 (1941).

[8] P. Auger and A. Rogozinski, Phys. Rev. **65**, 64 (1944).

TABLE I. Experiment II. Coincidences, per 10 hours, occurring between the master group M_1M_2 and the different analyzing counters F, G, G', H, K_1, K_2, K_3.

I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Hours of recording	cm Pb	$M_1M_2GG'-FH$ (1) or $M_1M_2FGG'H$ (2)			$M_1M_2GG'-FH$ or $M_1M_2FGG'H$ in coincidence with					
			K_1	K_2	K_3	K_1K_2	K_1K_3	K_2K_3	$K_1K_2K_3$	Δ
7	2.5	(1) 75	12	10.5	7.5	6	3	0	3	33
		(2) 66	3	3	4.5	9	3	12	22.5	9
29.8	5.0	(1) 56	7.7	8.4	6.7	1.7	3	1.3	8.4	18.8
		(2) 64.8	1.7	3.7	3.4	6.4	3.7	6	33	6.8
20.5	10.0	(1) 27.8	4.4	3.4	4.4	1.5	1	1.5	1	10.6
		(2) 26	1	0.5	0.5	1	1	0.5	20	1.5

$M_1M_2FGG'H$ which are accompanied by simultaneous discharges in the 7 possible combinations of counters of the upper set K_1, K_2, K_3. The last column Δ represents the differences between the frequency of $M_1M_2GG'-FH$ or $M_1M_2FGG'H$ and the sum of all the frequencies of the corresponding 7 types of coincidences listed in columns IV to X. These Δ values represent the frequency of events $M_1M_2GG'-FH$ or $M_1M_2FGG'H$ which are *not* accompanied by a simultaneous discharge in any of the upper counters K_1, K_2, K_3. The average frequencies (counts per 10 hours) of coincidences between the master group and just one, or just two, or all three counters K_1, K_2, K_3, were, respectively, 320, 80, and 170, regardless of any discharge which might have occurred in the lower set of counters. It results from these figures that the average frequency of those A showers, which discharge at least one of the counters K_1, K_2, or K_3 in coincidence with the master group, is $320+2\times80+170=650$ in 10 hours.

3. As we have mentioned in I, the chance coincidences could be neglected for the higher order coincidences reported there. In the present case, however, this factor has to be considered, mainly for the single-particle events $M_1M_2GG'-FH$, where larger thicknesses of lead were used. Although such an event is essentially a fourfold coincidence, the computation of the chance coincidences in the actual case involves coincidence rates of different orders, the most important contribution of which comes from the twofold coincidence rates between (a) the proper twofold coincidence rate M_1M_2 of the master group and (b) the proper twofold coincidence rate of the telescope GG'. The frequencies of the chance coincidences (per 10 hours), thus calculated, for $M_1M_2GG'-FH$ are, respectively, 19.2, 18, and 16 for lead thicknesses of 2.5, 5.0, and 10.0 cm. This shows that the corresponding Δ values for 5.0 and for 10.0 cm of lead could be due entirely to chance coincidences. For 10.0 cm of lead, the Δ value of 10.6, which is appreciably lower than the value of 16 which represents the calculated chance coincidence frequency, could be due to a fluctuation in the average number of the chance coincidences; in addition, it could be caused by a small contribution of chance coincidences arising from the fivefold coincidences $M_1M_2GG'K_1$, $M_1M_2GG'K_2$, and $M_1M_2GG'K_3$.

Incidentally, the above-mentioned reasons—apart from the fact that the geometrical arrangement of the counter telescope GG' presents a certain "leak," regarding the solid angle of GG' which is not entirely covered by the upper set of counters—makes uncertain, on the basis of the present data, any attempt to correlate with a non-ionizing particle the passage of a single penetrating particle through the lead absorber.

4. In order to obtain a clearer picture of the meaning of the experimental data of Table I concerning the density of particles which strike the lead absorber in case of events $M_1M_2GG'-FH$, a comparison was made in Table II between these events and the shower events which are respectively coincident with a discharge occurring in one or more of the upper counters K_1, K_2, K_3. For this purpose, the counting rates for $M_1M_2GG'-FH$ and $M_1M_2FGG'H$ were each reduced to a value of 100, and the counting rates of the corresponding higher order coincidences

were calculated accordingly. The equivalent three counting rates for coincidences between $M_1M_2GG'-FH$ or $M_1M_2FGG'H$ on one hand, and K_1, K_2, or K_3 on the other hand, were replaced by their sum. The same was done for the three counting rates involving K_1K_2, K_1K_3, or K_2K_3, instead of K_1, K_2, or K_3. In computing the values of Table II, the calculated chance coincidence rates of 19.2 and 18 were taken into account for 2.5 and 5.0 cm of Pb, respectively; the chance coincidence rate for 10.0 cm of Pb was taken equal to 10.6 in order to make the Δ value which corresponds to this thickness of lead equal to zero.

Discussion of Experiment II

Let us consider, in Table II, the data referring to single or shower events which occur below the lead and are associated with simultaneous discharges in the upper set of counters K_1, K_2, K_3. One can notice immediately the apparent fact that for all lead thicknesses, the single-particle events $M_1M_2GG'-FH$ are much more frequently accompanied by discharges in a single upper counter than the shower events $M_1M_2FGG'H$. These, on the contrary, are more frequently accompanied by discharges in two and mainly in three upper counters than the single-particle events. In particular, for 10 cm of Pb, the ratio between the percentages of events $M_1M_2GG'-FH$ or $M_1M_2FGG'H$, each accompanied by discharges in the upper set of counters, changes from $71:7.7\simeq 9$ when a discharge occurs in just one of the upper counters, to $6:77\simeq 1/13$ when a discharge occurs in all three upper counters K_1, K_2, K_3. This variation is of the order of magnitude of $9:1/13\simeq 100$. The obvious consequence which follows from these figures is that the mean density of particles which are associated, ***above*** the lead, with single-particle events $M_1M_2GG'-FH$ is very small in comparison with the corresponding density for the shower events $M_1M_2FGG'H$.

TABLE II. Experiment II. Relative values of counting rates for coincidences occurring between (1) $M_1M_2GG'-FH$, or (2) $M_1M_2FGG'H$, and the upper counters K_1, K_2, K_3.

cm Pb	$M_1M_2GG'-FH$ (1) or $M_1M_2FGG'H$ (2)	$M_1M_2GG'-FH$ or $M_1M_2FGG'H$ in coincidence with			Δ
		$(K_1+K_2+K_3)$	$(K_1K_2+K_1K_3+K_2K_3)$	$K_1K_2K_3$	
2.5	(1) 100	54	16	5.5	24.5
	(2) 100	16	36.5	34	13.5
5.0	(1) 100	60	16	22	2
	(2) 100	13.5	25	51	10.5
10.0	(1) 100	71	23	6	0
	(2) 100	7.7	9.6	77	5.7

This fact that a single-particle event $M_1M_2GG'-FH$, which is presumably caused by a mesotron, is usually associated with a very small number of ionizing particles in its immediate neighborhood, could be interpreted in two different ways: Either the mesotron belongs to a low density region (wing) of an A shower and, hence, is present at a relatively large distance from the core of the A shower (A shower hypothesis), or the mesotron is located in a shower of low particle density, other than an A shower. Such a shower could arise, for example, from collisions of the mesotron with electrons along its path in the air (collision-electron hypothesis).

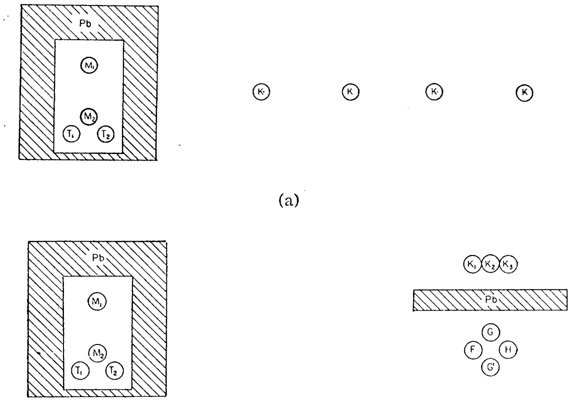
Thus, if the A shower hypothesis is correct, the mean density of particles which cover a certain relatively large area around the mesotron should be approximately constant all over this area. In other words, one should expect that the considered particle density at any point of this area would be approximately independent of the distance (a few meters) of this point from the mesotron trajectory since in the present case the mesotron would be located far from the high density region of its parent A shower.

In case the collision-electron hypothesis is correct, the just considered density of particles should be an essentially decreasing function of the distance from the mesotron trajectory. This follows from the fact that, on one hand, electrons arising from collision processes of mesotrons in air should have an increasing energy in order to reach points located at increasing distances from the parent mesotron, and, on the other hand, the probability of ejecting a collision electron of a certain energy decreases, in first approximation, as the square of that energy. A theoretical computation of this effect is given in the paper (III) which follows the present one.

Experiment III

As a consequence of these considerations further attempts were made to determine which one of the considered hypotheses is correct.

1. In the experiments I and II the master group could be discharged by both soft and penetrating particles of energies higher than the minimum energy of a few Mev which is necessary to penetrate the counter walls. In the experiments which are to be described, the master group selected only particles which are able to penetrate 10 cm of lead, and, in particular, those particles which emerge below the lead without being accompanied by a shower and are, therefore, classified as mesotrons. One can say that in the latter case the master group worked as a kind of a mesotron selector.



(a)

(b)

FIG. 3. Counter arrangement in Experiment III.

Thus, the master group consisted of a vertical telescope in twofold coincidence M_1M_2 and, in addition, of two side counters T_1 and T_2 which could be connected in anticoincidence to M_1M_2 (Fig. 3). T_1 and T_2 were in most cases connected in parallel. The whole master group was surrounded by a lead shield 10 cm thick. According to what was explained above, the anticoincidence events $M_1M_2 - T_{1,2}$ were attributed to penetrating non-shower-producing particles, such as mesotrons. In some very rare cases, however, which will be discussed below, high energy soft particles might also produce such an anticoincidence event.

2. Two series of experiments were carried out. In the first, several analyzing counters were placed at different distances from the master group (Fig. 3a). In that way it was possible to obtain, from the same record of coincidences, the counting rate in an analyzing counter as a function of its distance from the mesotron selector. In the second series of experiments, a set of 7 analyzing counters, similar to the set described in experiment II, was used in order to investigate the penetrating power of the particles associated with those particles which discharge the master group (Fig. 3b). Since all the data obtained in these experiments, which were carried out in Chicago and at Echo Lake, are not yet analyzed and since similar experiments are still in progress, only part of the results will be reported here and summarized in Table III.

In Table III the first two columns I and II are self-evident; column III (1, 2) gives the proper counting rate (counts per 10 hours) of the master group for the two cases where only mesotrons ($M_1M_2 - T_{1,2}$) or both mesotrons and high energy soft particles (M_1M_2) are registered; column IV gives the counting rate (also per 10 hours) of discharges in an analyzing counter for different distances D of that counter from the master group; column V represents the ratio ν between the counting rates which figure in columns IV and III for events $M_1M_2 - T_{1,2}$. The last column VI gives the theoretical values for ν, which represent the ratio ν_{th} between (a) the frequency of discharges in a distant counter, arising from collision electrons ejected in air by those mesotrons which traverse the selector, and (b) the proper counting rate of the selector. The formula

TABLE III. Experiment III. Coincidences, per 10 hours, occurring between (1) the mesotron selector $M_1M_2 - T_{1,2}$, or (2) the master group M_1M_2, and an analyzing counter K.

I Hours of recording	II D in meters	III $M_1M_2 - T_{1,2}$ (1) or M_1M_2 (2)	IV $(M_1M_2 - T_{1,2})K$ (1) or M_1M_2K (2)	V $\nu = \frac{(M_1M_2 - T_{1,2})K}{M_1M_2 - T_{1,2}}$	VI ν_{th}
		Chicago; Altitude: 610 ft.			
50	0.5	(1) 2.7×10^4	19.7	7.1×10^{-4}	8.6×10^{-5}
34		(2) 3.4×10^4	48.3		
50	1.0	(1) 2.7×10^4	8.6	3.2×10^{-4}	4.2×10^{-5}
34		(2) 3.4×10^4	22		
50	2.0	(1) 2.7×10^4	5.2	1.9×10^{-4}	2.0×10^{-5}
34		(2) 3.4×10^4	13.3		
		Echo Lake; Altitude: 10,618 ft.			
51	2.0	(1) 5.0×10^4	15.3	3.1×10^{-4}	1.4×10^{-5}
26.5		(2) 6.2×10^4	67.4		
76	5.0	(1) 5.0×10^4	6.7	1.3×10^{-4}	0.5×10^{-5}
42		(2) 6.2×10^4	43.8		

for this ratio is derived in paper III and is given by

$$\nu_{\text{th}} = (BS/\pi D)\theta_{\max}(D, E_1).$$

Here, B is a constant factor which is equal to 10^{-2} for standard air if the effective area S of the counter, placed at a distance D from the selector, is expressed in m^2 and D in meters; $\theta_{\max}(D, E_1)$ is a function of D and of the minimum energy E_1 which is necessary for an electron to traverse the wall of the counter. Some of the calculated values for $\theta_{\max}(D, E_1)$ are given in Table IV.

In Table III the values of ν_{th} were computed for $S = 2.5 \times 10^{-2}$ m^2 and $E_1 = 2$ Mev. The altitude effect on ν_{th} was taken into account (see Altitude Effect, in III).

Discussion of Results of Experiment III

It was found that: (a) the frequency of discharges occurring in an analyzing counter in coincidence with a discharge in the mesotron selector is, at least for the first few meters, a strongly decreasing function of the distance D of this counter from the selector; (b) most of the discharges in any particular analyzing counter are only very occasionally accompanied by a discharge in other analyzing counters; and (c) the counting rates in these analyzing counters are considerably lower than those which are usually observed for A showers using unshielded counters separated by the same distance D.

A proof that the observed phenomena, in which only the passage of a mesotron through the selector $M_1M_2 - T_{1,2}$ is involved, are of a different nature from those which involve soft particles, is given by the experiments in which the side counters T_1 and T_2 are removed. In these experiments, the master group M_1M_2 could record, in addition to mesotrons, also the high energy soft particles which emerge with a large shower below a lead thickness of 10 cm. Although in this case the proper counting rate of the master group increased only by $\sim$25 percent, the corresponding increase in the counting rate of the analyzing counters was of the order of $\sim$300 percent. Moreover, the proportion of cases where multiple coincidences between the different analyzing counters occurred increased at the same time by an even more considerable factor.

Because of the strong dependence of the counting rate of an analyzing counter upon its distance from the selector, the observed phenomena seem so far to be in qualitative agreement with the collision-electron hypothesis. But, on the other hand, it is seen from Table III that there exists a considerable discrepancy between the experimental and theoretical values calculated on the basis of the collision-electron hypothesis. Therefore, it would be legitimate to conclude that at least part of the observed mesotrons belong actually to A showers. However, there is a possible explanation, which could account, at least partly, for the above-mentioned discrepancy.

As we have seen, the role of the mesotron selector is to register only those events in which the vertical telescope M_1M_2 is discharged, but not any of the side counters T_1 and T_2. It is well known that the great majority of these events can be attributed to single mesotrons emerging below the lead absorber which surrounds the selector. In two cases, however, the selector will fail in its function as mesotron selector.[9] First, the selector will miss all mesotrons which emerge below the absorber with a collision electron discharging one of the two side counters T_1 or T_2. This effect, however, reduces the counting rate of the distant counters by only a few percent. Second, a high energy soft particle emerging, for example, with a narrow shower accompanied by a few side particles, could discharge the telescope M_1M_2 and very occasionally miss both[10] side counters T_1 and T_2. Such an event will be recorded and considered naturally as being produced by a single mesotron. The influence of this effect on the counting rate of the distant counter will, on the average, be much more important than in the first case since a high energy soft particle has a much higher

TABLE IV. Values of $\theta_{\max}(D, E_1)$.

E_1 Mev \ D meters	1	2	5	10
2	0.53	0.50	0.41	0.30
4	0.42	0.40	0.34	0.27

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[9] See also Section C2 of the preliminary considerations.

[10] Counter inefficiencies are too small to contribute appreciably to such a double missing. On the other hand, the anticoincidence *circuit* is practically 100 percent efficient.

probability than a mesotron to be accompanied by a shower; hence, the probability of discharging the distant counter will, in first approximation, also increase in proportion to this effect. It was emphasized before that in connecting the anticoincidence counters into the circuit of the master group, one reduces the proper counting rate of the master group by ~ 20 percent, while the corresponding reduction of the counting rate in the distant counter is then ~ 75 percent. Therefore, it is easy to understand that in case several percent, out of about 80 percent of the discharges of the master group which are attributed to mesotrons, were actually due to high energy soft particles, the corresponding reduction in the counting rate in the distant counter could be appreciably higher than the observed ~ 75 percent. Consequently, the frequency of discharges in the distant counter, occurring simultaneously with a passage of a mesotron through the master group, might be actually much smaller. It should be pointed out, however, that the hitherto admitted occurrence of that particular narrow shower below a lead thickness of 10 cm is probably a very infrequent event and, hence, could account only partly for the observed large discrepancy.

It would be possible to obtain a more precise idea of the importance of the just-described effect—and to reduce it eventually—in using, for example, counters of a smaller size for the telescope M_1M_2 and of a larger size for the side counters T_1 and T_2. Considerable difficulty would, however, arise then from a very strong reduction of the observed counting rates which are already very low in the present investigations.

This is the characteristic difficulty in counter experiments since it is not known whether a discharge in a counter was produced by a single particle or by several particles. Therefore, a few cloud-chamber photographs[11] of the particles which discharge the mesotron selector would be of great value in analyzing this effect.

The altitude effect, which should be different for each of the two hypotheses, could throw some light on the problem considered here. In case of the collision-electron hypothesis, the observed effect should increase parallel to the increase in the intensity of the mesotron component of the cosmic radiation. In the alternate case, this effect should follow the increase in the frequency of the A showers. We found that between Chicago and Echo Lake the increase in the intensity of the mesotron component is 1.9, whereas the increase of the frequency of A showers of an average extension is ~ 7. The observed increase in the counting rate of a distant counter is ~ 3 and lies between these two values. But before a significant comparison regarding the altitude effect can be made, it will be necessary to carry out further measurements in order to extend the common range of the distance D for the two altitudes and to prolong the time of observation.

CONCLUSIONS

By way of conclusion, we shall point out that: (a) Counter experiments are practically unable to give unambiguous information regarding the presence of mesotrons in the dense part of A showers. (b) Mesotrons were found to be associated with particles of very low density, which could be considered either as belonging to A showers or as collision electrons ejected by these mesotrons along their path in the air. (c) Although the hypothesis of mesotrons accompanied by collision electrons seems to agree qualitatively with the experimental results so far obtained, the experimental values, however, are considerably higher than those given by a theoretical calculation for this case. Therefore, it would be legitimate to conclude that at least part of the observed mesotrons actually belong to A showers. But on the other hand, explanations are indicated which might account, at least partly, for the above-mentioned qualitative disagreement. Thus, only after these explanations are tested by experiment will it be possible to decide more definitely as to the presence of mesotrons in A showers.

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[11] Valuable photographs of tracks in a cloud chamber controlled by distant counters were obtained, at an altitude of 3200 meters, by P. Auger and J. Daudin, Comptes rendus **209**, 481 (1939).