but the probable differences in the spectra obtained in the two cases make detailed interpretation difficult.

VI. ACKNOWLEDGMENTS

The authors are indebted to Mr. F. R. Perry for his interest in and encouragement of the work and to Sir Arthur P. M. Pleming, C.B.E., D. Eng., Director of Research and Education, and to Mr. B. G. Churcher, M.Sc., M.I.E.E., Manager of Research Department, Metropolitan-Vickers Electrical Company, Ltd., for permission to publish this paper.

PHYSICAL REVIEW VOLUME 74, NUMBER 4 AUGUST 15, 1948

Penetrating Particles in Extensive Air Showers

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(Received May 3, 1948)

Penetrating particles in extensive air showers have been studied at 4300- and 3260-m elevations. The particles capable of penetrating 14 cm lead are about 1 per 30 shower particles at 3260 m and 1 per 25 at 4300 m. The number of penetrating particles is reduced by a factor 1.8 when the lead is increased from 15.5 to 39 cm, and the density of the penetrating particles diminishes by a factor 1.7 between 4300 and 3260 m elevation. These facts imply the penetrating particles are very numerous and have too low average energy to be mesons coming from the top of the atmosphere. Further experiments show that they are not produced multiply in lead shields above the counters. This fact, together with the independence of their number on the atomic number of the absorber, seems to indicate they are not produced by photons.

SECTION A

In order to extend our knowledge about the penetrating particles in extensive air showers, experiments were performed last summer at Echo Lake and Mt. Evans, Colorado (elevations 3260 and 4300 meters, respectively), in which the particles of the showers were recorded with unshielded counters and with counters under lead. The counter and lead arrangement used for a large part of the data taken at Echo Lake and all of the data taken at Mt. Evans are shown in Fig. 1. For brevity in reference we shall call this experiment *A*.

In experiment *A* the area of the shielded counters was held constant at 293 cm^2 each, but the area of the unshielded counters was changed periodically among the values 48, 98, and 293 cm^2.

The counters had brass walls, $\frac{1}{2}$ mm thick, were one inch in diameter and were filled with a self-quenching gas mixture. Almost all were 16 inches in length and had an active area of 98 cm^2. The largest counter area referred to above, 293 cm^2, was composed by connecting three such counters in parallel. The smallest area, 48 cm^2, was obtained with single counters eight inches in length and one inch in diameter. The circuits and the counter plateaus were checked daily during the course of the experiments.

As Fig. 1 shows, the counter separations were about two meters. Cocconi, Loverdo, and Tongiorgi[1] have shown that the number of showers recorded with a counter arrangement similar to that of experiment *A* is not sensitive to changes of the counter-separation between two and eight meters.

The lead shielding the lower counters was composed of lead pigs, cut so as to nest tightly together, and covered with lead sheets. The counters were not perfectly shielded with lead at the ends, but the lead below, on the sides and above the counters was much longer than the counters themselves (see Fig. 1b). The smallness of the counter area facing the ends, the small solid angle of the openings and the low intensity at large zenith angles combine to make the relative probability of a shower particle entering the counter through the unshielded ends less than 10^{-3}. The lead below the counters was five

[1] G. Cocconi, A. Loverdo, and V. Tongiorgi, Phys. Rev. **70**, 841 and 852 (1946).

cm thick, that at the sides was ten cm thick and that above the counters was fourteen cm thick, sufficient to exclude electrons of energy below about 3×10^{10} ev in the vertical direction. For cascade showers in air arising from primaries of energy 10^{12} to 10^{15} ev at the top of the atmosphere, the fraction of the electrons above 3×10^{10} ev at Echo Lake is less than 10^{-3}.

The apparatus was housed in a light canvas tent so that there should be essentially no shower-producing material above the unshielded counters. The counters were all far enough apart so that showers produced in the lead, whether of electrons or penetrating particles, would not likely discharge more than one counter. Hence the coincidences recorded were in general due to multiplication of the showers in the air and not in local materials.

Impulses from the four unshielded counters were fed into a discriminator circuit (with 0.9 microsecond resolving time) which selected fourfold and threefold coincidences (denoted by $4S$ and $3S$, respectively, where S stands for "soft rays"). Similarly, the impulses from the shielded counters were fed into a discriminator that selected fourfold, threefold and twofold coincidences and single pulses (denoted by $4H$, $3H$, $2H$, and $1H$, respectively, where H stands for "hard rays"). Coincidences denoted by nS or nH include all coincidences of at least n counters; thus $3S$ includes both threefold and fourfold coincidences, etc. Hence, in computing standard errrors of a ratio of rates such as $3S/4S$, it must be kept in mind that the $3S$ and $4S$ counts were not independent.

TABLE I. Coincidences recorded in experiment A. (Fig. 1.)

	Echo Lake (3260 m)			Mt. Evans (4300 m)		
Area° (cm²)	48	98	293	48	98	293
Time (min.)	10,102	10,167	5585	4569	2538	1427
$3S$	1173	3059	7325	910	1304	3400
$3S+1H$	509	1013	1181	408	409	550
$3S+2H$	164	276	242	194	142	104
$3S+3H$	78	95	68	86	54	32
$3S+4H$	29	32	22	40	18	10
$4S$	298	829	2267	271	377	1031
$4S+1H$	182	407	591	190	196	292
$4S+2H$	92	165	180	125	94	84
$4S+3H$	56	77	60	67	38	27
$4S+4H$	26	26	20	35	14	10
$2H$	1442	1404	861	1276	697	388
$2H$*	1010	970	620	920	500	280
$3H$	123	110	78	125	78	34
$4H$	31	33	22	41	19	10
total time		25,854			8534	
total $2H$*		2600			1700	
total $3H$		311			237	
total $4H$		86			70	

° Area refers to unshielded counters. Area of shielded counters was fixed at 293 cm².
* Corrected for chance coincidences with 0.9 microsec. resolving time.

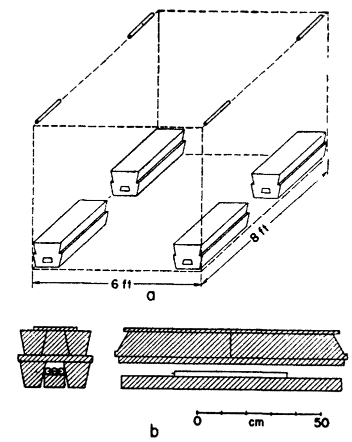

FIG. 1. Arrangement of counters and lead in experiment A.

Pulses from the two discriminator circuits were fed into coincidence units which selected (with a 3.5-microsecond resolving time) coincidences of the S counters with the H counters. Thus thirteen different coincidence combinations were recorded simultaneously, as listed in Table I, which contains all of the data of experiment A.

Conclusions Drawn from Experiment A

1. Density Distribution for All Shower Particles

In Fig. 2, the logarithms of the $3S$ and $4S$ coincidence rates are plotted against the logarithms of the counter area. Within statistical errors (too small to appear outside the circles), the data are in agreement with straight lines, all of the same slope, 1.40, as drawn in Fig. 2. This characteristic of the showers has been observed before[1-3] and indicates that the frequency of incident showers, as a function of the total particle density, Δ (capable of penetrating $\frac{1}{2}$ mm of brass), follows the equation $f(\Delta)d\Delta=K\Delta^{-\gamma}d\Delta$ with $\gamma=2.4$ and $K(4300)/K(3260)=1.8$.

On the assumption that the form of the fre-

[2] P. Auger and J. Daudin, J. de phys. et rad. 6, 233 (1945).
[3] J. Daudin and A. Loverdo, J. de phys. et rad. 8, 233 (1947).

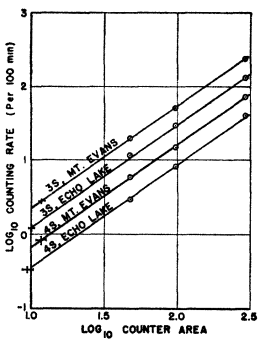

FIG. 2. Dependence of threefold and fourfold coincidence rates of the unshielded counters on counter area. Crosses indicate threefold and fourfold coincidence rates of shielded counters of area 293 cm².

quency-density relation is a power law as given above, an independent value for γ can be derived from the ratio of threefold to fourfold coincidences.[2,3] Since the probability of missing a counter is $e^{-A\Delta}$ and the probability of hitting a counter is $1-e^{-A\Delta}$ (A being the counter area), we have

$$(4S)=\int_0^\infty (1-e^{-A\Delta})^4 K\Delta^{-\gamma}d\Delta =KA^{\gamma-1}(-\gamma)![-4+6(2)^{\gamma-1}-4(3)^{\gamma-1}+(4)^{\gamma-1}].$$

$$(3S)=\int_0^\infty [(1-e^{-A\Delta})^4+4e^{-A\Delta}(1-e^{-A\Delta})^3]K\Delta^{-\gamma}d\Delta =KA^{\gamma-1}(-\gamma)![-6(2)^{\gamma-1}+8(3)^{\gamma-1}-3(4)^{\gamma-1}].$$

The ratio is a function of γ alone. Experimentally, we find the average ratio $(4S)/(3S)=0.296\pm0.004$, whereas if $\gamma=2.40$ (derived from the slopes in Fig. 2) the ratio should be 0.340.

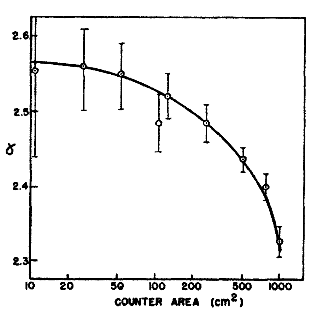

FIG. 3. Variation of effective value of γ with counter area, as computed from data of Cocconi, Loverdo and Tongiorgi (reference 1).

The experimental ratio $(4S)/(3S)$ would indicate $\gamma=2.55$. Thus, the two determinations of γ are not in good agreement.

Auger and Daudin[2] have made measurements of γ by observing the ratio of threefold to twofold coincidences between counters of surface area about 150 cm². They found γ to be a decreasing function of altitude, varying linearly with the pressure and having the values 2.66 at 50 m, 2.58 at 980 m, 2.50 at 2060 m, and 2.46 at 2860m. They have made the observation that even at a fixed altitude γ must not be a true constant, but must decrease slowly as Δ decreases; otherwise the total number of particles must diverge.

Recently, Maze, Fréon, and Auger[4] have confirmed the decrease of γ with altitude, with measurements in an airplane. They report $\gamma=2.67\pm0.01$ at sea level and 2.41 ± 0.05 at 22,000 ft. Calculations by Cocconi,[5] however, indicate that the cascade theory would predict an increase of γ with altitude, rather than a decrease as found by the above authors.

Cocconi, Loverdo, and Tongiorgi[1] have measured threefold and fourfold coincidence rates as functions of counter area over a wide range of areas. At 2200 meters' elevation, the dependence of counting rates upon area indicates $\gamma=2.45$ before correction. A correction for showers generated in the roof raised this value to 2.55. However, if one examines their ratios of threefold to fourfold coincidences, one finds that γ apparently depends on the counter area, as indicated by the graph in Fig. 3. This variation is as predicted by Auger and Daudin[2] and has been discussed in considerable detail by Daudin and Loverdo.[3] The same trend appears in our data but is not so apparent because we did not vary the counter area by so large a factor.

A possible source of error in the value of γ deduced from the variation of coincidence rates with counter area arises from the fact that the counters of different area were not of the same shape. The largest counters (in the experiments of Cocconi *et al.* as well as our own) were made up of several cylinders placed side by side and resembled plane areas, while the smaller counters were single cylinders and thus more nearly re-

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[4] R. Maze, A. Fréon, and P. Auger, Phys. Rev. **73**, 418 (1948).
[5] G. Cocconi, Phys. Rev. **72**, 964 (1947).

sembled spherical detectors. Thus the effective area of the counters, for showers incident with a large zenith angle, is reduced by a larger factor for the larger counters. This makes the variation of counting rate with counter area appear less strong than it should; i.e., it reduces the apparent value of γ.

Another source of error is the barometric fluctuations. The counting rates with different counter areas were measured at different times. Since the barometric coefficient for extensive showers is very high (10 to 20 percent per cm Hg), the apparent variation of counting rate with area may have been appreciably influenced by pressure variations. These would not have any effect, however, on the determination of γ through the ratio $4S/3S$, because the $4S$ and $3S$ rates with any given counter area were measured simultaneously.

Because of all the above considerations, we do not think the discrepancy between the values of γ deduced in our experiment is large. In fact, both values are in agreement with measurements of other authors. It was not our purpose to determine γ with great precision, but rather the relative numbers of penetrating and soft particles in the showers, and in the analysis given below, a variation of 0.1 in the value of γ is not serious. Therefore, in the calculations to follow we shall take $\gamma=2.5$.

2. *All Extensive Air Showers Contain Penetrating Particles, and All Extensive Penetrating Showers Are Accompanied by Extensive Electron Showers*

This conclusion is in agreement with that of Cocconi, Loverdo, and Tongiorgi.[1]

In Table II we list the relative numbers of $3H$ and $4H$ coincidences that were accompanied by threefold and fourfold coincidences of the unshielded counters. It may be seen that when three of the counters under lead were struck, the probability was not very large that the fourth counter be struck also; but the probability was very high that three or all four of the unshielded counters be discharged. When all four counters under lead were struck, it was a relatively rare event for one or more than one of the unshielded counters to be missed, even when the area of the unshielded counters was $\frac{1}{6}$ that of the counters under lead. These facts imply that practically all of the extensive showers of penetrating particles were accompanied by extensive electron showers, and that the number of electrons was large compared with the numbers of particles that could penetrate 14 cm of lead.

TABLE II. Relative numbers of extensive penetrating showers accompanied by coincidences of unshielded counters.

Location	Area* cm²	$\frac{3H+3S}{3H}$	$\frac{3H+4S}{3H}$	$\frac{4H+3S}{4H}$	$\frac{4H+4S}{4H}$
Echo Lake	48	78/123	56/123	29/31	26/31
Mt. Evans	48	86/125	67/125	40/41	35/41
Echo Lake	98	95/110	77/110	32/33	26/33
Mt. Evans	98	54/78	38/78	18/19	14/19
Echo Lake	293	68/78	60/78	22/22	20/22
Mt. Evans	293	32/34	27/34	10/10	10/10

* This area refers to the unshielded counters. The area of the counters under lead was held constant at 293 cm².

In principle, one could calculate the average ratio of soft particles to hard particles from the data of Table II. The results, however, would depend sensitively on the very small numbers of the $3H$ and $4H$ counts that were not accompanied by a $3S$ or $4S$ coincidence. Evidence will be presented below that a comparatively large number of locally generated penetrating showers occurred, not associated with extensive air showers. Mostly, these were not recorded in Experiment *A* because of the large counter separations; but if a small fraction of the local penetrating showers succeeded in discharging more than one of the counters under lead, they could be responsible for many of the penetrating showers in which $3S$ and $4S$ coincidences were not recorded.

In Fig. 4 are shown the relative numbers of $3S$ and $4S$ coincidences in which various numbers of penetrating particles were recorded. These ratios are functions of the area of the unshielded counters, because the average density of particles in the showers that are recorded increases as the area is reduced, thus increasing the relative chance of detecting penetrating particles. The $3S$ and $4S$ coincidences could not have been appreciably affected by local showers, because the counting rates were high and the counters were well separated with no shower producing material above them (see Fig. 1).

The solid curves in Fig. 4 have all been calcu-

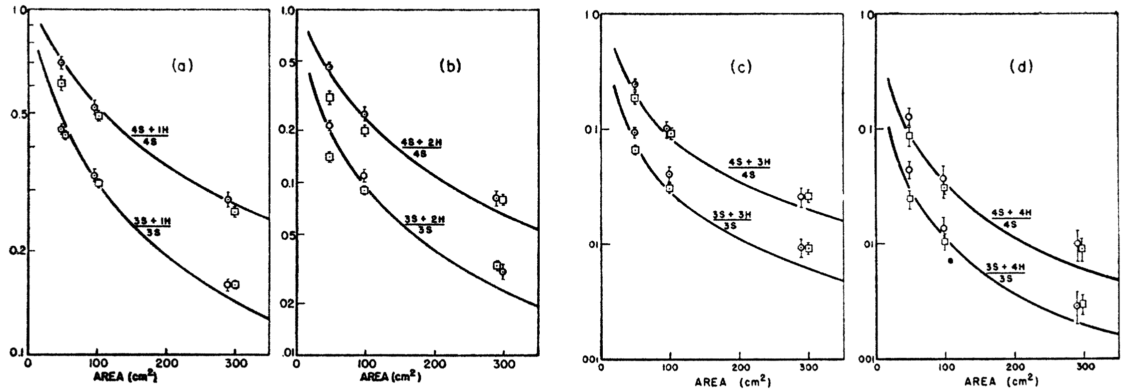

FIG. 4. Relative numbers of S showers (in unshielded counters) that are accompanied by H counts (in the shielded counters), as functions of the area of the unshielded counters. Circles give data at 4300 m; squares give data at 3260 m elevation. Solid curves are calculated for one penetrating particle per 29 shower particles.

lated under the assumption that the ratio of soft particles to penetrating particles is a constant throughout the showers. To illustrate the calculations we give the deduction of the formula representing the $4S+1H$ coincidence rate:

$$(4s+1H)=\int_0^\infty (1-e^{-A\Delta})^4(1-e^{-A'\Delta/N})K\Delta^{-\gamma}d\Delta$$

$$=KA^{\gamma-1}\int_0^\infty (1-e^{-x})^4(1-e^{-\beta x})x^{-\gamma}dx,$$

$$\text{with } \beta=A'/AN$$

$$=KA^{\gamma-1}(-\gamma)![-4+6(2)^{\gamma-1}-4(3)^{\gamma-1}$$
$$+(4)^{\gamma-1}-(\beta)^{\gamma-1}+4(1+\beta)^{\gamma-1}$$
$$-6(2+\beta)^{\gamma-1}+4(3+\beta)^{\gamma-1}-(4+\beta)^{\gamma-1}].$$

In these equations A is the area of the unshielded counters and A' is the total area of all four counters under lead, N is the ratio of all particles in the shower to the penetrating particles, and $K\Delta^{-\gamma}d\Delta$ is the frequency of showers with total particle density between Δ and $\Delta+d\Delta$. The curves have been drawn corresponding to $N=29$.

The agreement of the calculations with the experimental results is apparently satisfactory. The agreement would be better if we had used a slightly lower value for N at Mt. Evans and a slightly higher value at Echo Lake. It may be seen from Fig. 4 that almost all the points for the higher elevation lie above the points for the lower elevation, indicating relatively more penetrating particles in the showers at the higher elevation.

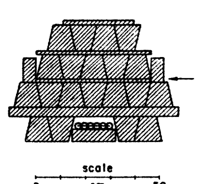

FIG. 5. Arrangement of shielded counter and lead in experiment B. In part of this experiment, the lead above the level of the arrow was removed.

Perfect agreement between the data and the calculated curves should not be expected, for neither N nor γ is more than an empirical constant. In particular, the relative number of mesons and electrons might be expected to vary with the geometric distance from the core of the shower and with the energy of the shower. As one increases the area of the unshielded counters, one does not change appreciably the average distance to the core of the showers recorded, but one decreases the average primary energy because smaller showers are recorded.

The associated production of electron showers and showers of penetrating particles has been observed in the cloud chamber by Fretter.[6] He observed no examples of production of penetrating showers by electronic radiation, but found that in more than half of the examples of penetrating showers, high energy electronic radiations was simultaneously produced. We think it is likely that the Auger showers in the atmosphere are fundamentally the same as the showers observed by Fretter, differing from them only in the magnitude of the energy and the total number of particles. In the large Auger showers

[6] W. B. Fretter, Phys. Rev. **73**, 41 (1948).

which we recorded, our data seem to indicate that all penetrating showers involve simultaneous production of electronic radiation, and all electronic showers involve simultaneous production of showers of penetrating particles.

3. *Further Evaluation of N*

If one accepts the conclusion that all extensive penetrating showers are associated with extensive electron showers, the most direct way to evaluate the ratio of electrons to penetrating particles is as follows. The probability of a coincidence being recorded is a function only of the product $A\Delta$, the area of the counters times the density of shower particles. Therefore, the area of the unshielded counters which would give the same threefold and fourfold coincidence rates, as are obtained with the counters under lead, bears a ratio to the area of the shielded counters which is the same as the ratio of penetrating particles to total particles per square meter. This principle is independent of the precise form of the frequency-density distribution law.

In Fig. 2, the crosses indicate the $3H$ and $4H$ coincidence rates found at Echo Lake and Mt. Evans. Extrapolation of the $3S$ and $4S$ counting rate *vs.* area curves shows that the $3S$ and $4S$ rates would equal the $3H$ and $4H$ rates if the area of the unshielded counters were reduced to 11.9 cm^2 at Echo Lake, or 9.9 cm^2 at Mt. Evans. Since the area of the unshielded counters was 293 cm^2, N must equal 30 at Echo Lake and 25 at Mt. Evans. These results are in very good agreement with the data given in Fig. 4.

4. *Variation with Altitude*

The chief purpose of these experiments was to gain some indication as to whether the penetrating particles in Auger showers are principally of local origin, as has been concluded by several authors,[7–9] or are produced at high altitude in the act which initiated the shower, as might be concluded from the theory of Lewis, Oppenheimer, and Wouthuysen[10] or inferred from recent data of Cocconi and Greisen.[11] By local production we mean production in the lead immediately surrounding the counters by the photons in the air showers.

TABLE III. Absorption of the penetrating particles in extensive air showers.

Pb thickness Time (min.)	15.5 cm 3614	39 cm 7639
$3S$	1077	2225
$4S$	326	679
$3S+H$	154	189
$4S+H$	72	115
$(3S+H)/3S$	0.143 ± 0.011	0.085 ± 0.006
$(4S+H)/4S$	0.22 ± 0.023	0.169 ± 0.014

It was thought that if the penetrating particles are of local origin, they would appear to be in equilibrium with the photons and electrons of the showers, whereas if they are of distant origin, the relative number of electrons and penetrating particles should vary with altitude. In fact, if the penetrating particles are mesons produced near the top of the atmosphere, they should be of high average energy at Echo Lake and should not change much in number between Mt. Evans and Echo Lake.

Experimentally, we find the average ratio of $3H$ and $4H$ coincidence rates of Mt. Evans (4300 m) to those at Echo Lake (3260 m) is 2.32 ± 0.18. This is an even larger change than occurs in the $3S$ and $4S$ rates, for which the average ratio between Mt. Evans and Echo Lake is 1.79 ± 0.03. Therefore, the density of "penetrating" particles in the showers is reduced even more than the density of electrons in traveling from Mt. Evans down to Echo Lake. The same result appears in the sections above where the average ratio of electrons to penetrating particles was shown to be about 29 at Echo Lake but only 24 at Mt. Evans.

If the frequency of extensive penetrating showers with density between Δ and $\Delta+d\Delta$ varies as $\Delta^{-\gamma}d\Delta$ with the same value of γ as that which applies for all particles in the showers, the density of penetrating particles must be reduced, between 4300 and 3260 meters elevation, by a factor $(2.32\pm0.18)^{1/\gamma-1}=1.75\pm0.09$. Ordinary mesons occurring singly and not associated with extensive showers decrease in intensity only by a factor of 1.3 between the same two elevations.

The strong reduction in average density of penetrating particles between the two elevations

[7] G. Cocconi and C. Festa, Nuovo Cimento **3**, 293 (1946).
[8] D. Broadbent and L. Janossy, Proc. Roy. Soc. **190**, 497 (1947), and **192**, 364 (1948).
[9] G. Salvini and G. Tagliaferri, Phys. Rev. **73**, 261 (1948).
[10] H. W. Lewis, J. R. Oppenheimer, and S. A. Wouthuysen, Phys. Rev. **73**, 127 (1948).
[11] G. Cocconi and K. Greisen, Phys. Rev. **74**, 62 (1948).

may be an effect either of absorption and decay, or of scattering and initial angular divergence. In either case, it is entirely inconsistent with the hypothesis that the particles are mesons produced near the top of the atmosphere in the act which initiated the shower. It does not, of course, prove that the particles are locally produced by the gamma-rays. But if the particles are locally produced, the absorption appears even more pronounced, for the "true" absorption must be partially compensated by production of some particles between Mt. Evans and Echo Lake. In other words, if the penetrating particles are locally produced mesons, their spectrum is very soft.

SECTION B

Absorption of the Penetrating Particles

A second experiment was performed at Echo Lake in order to measure the absorption of the penetrating particles of the extensive air showers in lead. The four unshielded counters were of 98 cm² area arranged as in experiment A. Under lead we had a single counter of area 586 cm², composed of six counters in parallel, as shown in Fig. 5. The thickness of lead above this counter was alternately 15.5 and 39 cm of lead. We shall refer to this absorption experiment as experiment B.

The data recorded are given in Table III. From the ratio $(3S+H)/3S$ with 15.5 cm of lead, we deduce (as outlined above in part b of Section A) the value 44 ± 4 for N, the ratio of the total number of shower particles to those capable of penetrating 15.5 cm of lead. Similarly, from the data with 39 cm of lead we deduce $N=83\pm7$, the ratio of all particles to those capable of penetrating 39 cm of lead. Since the total number of particles above the absorber is independent of the amount of lead, the factor of absorption between 15.5 and 39 cm is given by the ratio of these two values of N, which equals 0.54 ± 0.07. From the ratio $(4S+H)/4S$ with 15.5 and 39 cm lead, one deduces a smaller absorption (0.72 ± 0.13), but the statistical error is considerably larger. Since the fourfold coincidences are counted with the threefold coincidences in the $3S$ and $3S+H$ rates, the average absorption factor is 0.54 ± 0.07.

If the penetrating particles are mesons incident on the lead from the air, this absorption in lead appears very strong. From the data of Rossi and collaborators,[12] the ordinary mesons not associated with air showers are much less strongly absorbed at Echo Lake. Of those which can penetrate 15.5 cm only 17 percent are absorbed in an additional 23 cm of lead. On the other hand, if the penetrating particles are locally produced in the lead, the absorption must be at least as great as if they are incident from the air.

The implications are: (1) Whether the "penetrating" particles are produced locally or not, their average range in lead is not very great. (2) If the particles are locally produced in the lead, the primaries that produce them also have a short range. (3) If the particles are ordinary mesons, the mean energy is too small to be consistent with the hypothesis that the mesons are produced at the top of the atmosphere. Thus, the strong absorption in lead is consistent with the strong decrease in the atmosphere, and leads to the same conclusion.

The results of this experiment incidentally imply that the quantity N, referred to above, is a function of the amount of absorber placed above the shielded counters, and hence must be expected to vary from one experiment to another in which a different absorber thickness is used.

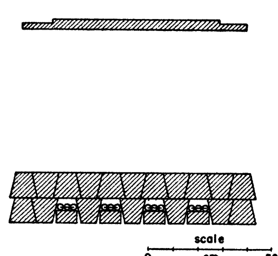

FIG. 6. Arrangement of shielded counters and lead in experiment C_1.

SECTION C

Search for Local Production of the Penetrating Particles in Extensive Showers

Experiment C_1 differed from Experiment A in that the shielded counters were placed much closer together, as shown in Fig. 6, and part of the lead shielding above the counters was raised about two feet. These changes were made to

[12] B. Rossi, K. Greisen, J. C. Stearns, D. K. Froman, and P. G. Koontz, Phys. Rev. 61, 675 (1942).

enhance the detection of multiple groups of penetrating particles locally produced in the lead. With the counter arrangement of Fig. 6, it was possible for a single particle striking the lead to generate a shower of penetrating particles which would discharge several of the shielded counters. In experiment A such an event was highly improbable.

A fixed area, 98 cm^2, was used for the unshielded counters in Experiment C, and the experiment was performed only at 3260 m elevation. Table IV summarizes the results, together with the comparable data of experiment A.

TABLE IV. Comparison of experiment C_1 and experiment A with 98 cm^2 area of unshielded counters.

	Experiment C_1	Experiment A
Time (minutes)	4106	10167
$3S$ rate*	27.7 ±0.8	30.1 ±0.5
$4S$ rate	8.3 ±0.4	8.2 ±0.3
$2H$ rate**	306.0 ±3	10.0 ±0.3
$3H$ rate	11.1 ±0.5	1.20 ±0.07
$4H$ rate	0.61 ±0.12	0.33 ±0.04
$(3S+1H)/3S$	0.268±0.013	0.331±0.009
$(4S+1H)/4S$	0.45 ±0.03	0.49 ±0.02
$(3S+2H)/3S$	0.084±0.008	0.090±0.005
$(4S+2H)/4S$	0.18 ±0.02	0.20 ±0.014
$(3S+3H)/3S$	0.032±0.005	0.031±0.003
$(4S+3H)/4S$	0.073±0.014	0.093±0.010
$(3S+4H)/3S$	0.009±0.003	0.010±0.002
$(4S+4H)/4S$	0.029±0.009	0.031±0.006

* All rates are per 100 minutes.
** Corrected for chance coincidences.

These data show no evidence for an increase in the fraction of the Auger showers ($3S$ and $4S$ coincidences) in which groups of penetrating particles were recorded. Therefore, we must conclude either that the penetrating particles observed in the showers are not produced locally, or that the penetrating particles are produced singly rather than in groups. In the latter case, the probability of detecting a coincidence of several shielded counters with the unshielded ones would not be strongly affected by the separation of the counters.

Experiment C_2 differed from C_1 only in that two of the counter groups under the lead were disconnected. The two remaining counter groups under lead were alternately adjacent groups and more distant groups. This experiment was made in order to investigate further the effect of the counter separations. The data are given in Table V. The spacings listed in the top row were measured from center to center of the counters. The minimum amount of lead between the counters, in experiment C_2 as well as in C_1, was 8 cm.

The statistical errors in experiment C_2 are large, but nevertheless the data show that the penetrating showers accompanying extensive air showers do not depend strongly on the separation of the counters. Considering both experiments C_1 and C_2, one may say that a coincidence of two counters under lead, caused by the particles in an extensive air shower, is just as likely to occur when the counters are two meters apart as when they are six inches apart. This is in diagreement with the experimental results of Salvini and Tagliaferri,[9] but in agreement with other experiments of Cocconi and Greisen.[11] In addition to indicating that the penetrating particles are not produced locally (or are produced singly), it confirms our belief that the "penetrating particles" are not high energy electrons in the core of the showers.

In sharp contrast to the above conclusions regarding the penetrating showers *accompanying* extensive air showers, we reach very different conclusions for the penetrating showers *not accompanied* by air showers. In Tables IV and V it may be seen that the $2H$, $3H$, and $4H$ coincidence rates were very strongly increased when the counter separation was reduced, whereas the number of these coincidences associated with air showers remained constant.

With the small counter separations, a significant fraction of the $2H$, $3H$, and $4H$ coincidences were without doubt caused by single ordinary mesons travelling almost horizontally, and by knock-on electrons produced by such mesons in the lead. In order to discover whether

TABLE V. Coincidence rates as function of counter spacing, with only two counter groups under lead.

Counter spacing	7 inches	14 inches	21 inches
Time (minutes)	365	1051	587
$3S$*	31 (114)	26 (269)	28 (165)
$3S+1H$	8.5 (31)	5.3 (56)	7.7 (45)
$3S+2H$	1.4 (5)	1.1 (12)	1.4 (8)
$4S$	7.7 (28)	7.3 (77)	7.0 (41)
$4S+1H$	2.7 (10)	2.7 (28)	3.4 (20)
$4S+2H$	0.6 (2)	0.8 (8)	1.2 (7)
$2H$**	100 (366)	18 (199)	7.3 (47)

* Rates are per 100 minutes. The numbers in parentheses tell the numbers of counts recorded.
** Correction for chance coincidences was 0.7 count per 100 minutes

TABLE VI. Coincidence rates with two counter groups under 29 cm Pb.

Counter spacing	7 inches	
Time (minutes)	850	
$3S$	28	(239)*
$3S+1H$	2.9	(25)
$3S+2H$	0.35	(3)
$4S$	8.9	(76)
$4S+1H$	1.5	(13)
$4S+2H$	0.2	(2)
$2H$	79**	(676)

* Rates are per 100 minutes. The numbers in parentheses indicate the numbers of counts recorded.
** Correction for chance coincidences was one percent of rate.

or not all of the increase in counting rates could be so explained, experiment C_2 was repeated with twice as much lead above the counters (see Fig. 7). The data are given in Table VI. If the $2H$ coincidences were almost entirely due to mesons travelling horizontally, the rate should not have been affected by increasing the amount of lead above the counters. If anything, the $2H$ rate should have been increased since the amount of lead on the sides was reduced. Instead, we find that the $2H$ rate was diminished from 100 ± 5 (see Table V) to 79 ± 3.

Thus we have evidence for very large numbers of penetrating showers locally produced in the lead, but not accompanied by extensive air showers.[11] The absorption between 15 and 29 cm indicates that neither the primaries nor the secondaries have a very long range in lead. The $2H$ coincidence rates with different counter separations (Table V) indicate that the secondaries in these showers have a very wide angular spread. The small ratios of $3H$ to $2H$ and $4H$ to $3H$ indicate that the number of particles is in general small in such showers.

The nearly isotropic distribution of the particles and the great frequency of the penetrating showers not accompanied by extensive air showers make it seem plausible that they have caused some of the coincidences of the shielded counters even in experiment A where the counters were two meters apart. This may account particularly for many of the twofold coincidences of H counters observed in experiment A unaccompanied by $3S$ or $4S$ coincidences.

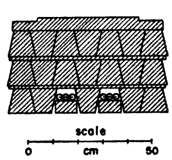

FIG. 7. Arrangement of shielded counters and lead used in part of experiment C_2 (data in Table VI).

DISCUSSION

It has been shown that the extensive showers contain many penetrating particles which cannot be mesons coming from the top of the atmosphere because their density diminishes too rapidly with atmospheric depth and with increasing thickness of the lead that they are required to penetrate. In fact, the relative density of penetrating and soft particles is almost the same at 4300 as at 3260 meters' elevation, and not very different at these elevations from the values found by Cocconi and by Broadbent and Janossy[8] at 2200 meters and at sea level. It seems thereby implied that the penetrating particles are of comparatively local origin, produced in the air not many radiation lengths above the point of observation. On the other hand, no evidence could be found for production of groups of penetrating particles, by the particles in extensive air showers, in a lead shield. These facts seem to present a contradiction, because phenomena that take place abundantly nearby in the air should also occur abundantly in the lead.

Suggestions for resolving the contradiction are: (1) the penetrating particles may be produced locally by photons in the air showers, but the production may be mostly of single particles rather than groups; or (2) the particles responsible for the production of the penetrating particles may have a short mean path in air, and be very much more abundant a few thousand meters above the point of observation than at the point of observation.

Under these conditions the penetrating particles could be mesons with rather large angular divergence and moderately low energies. This suggestion fits in well with a sort of cascade multiplication of the penetrating particles, which has passed its maximum before reaching 5000 meters' elevation. Intermediate particles involved in such cascade multiplication may be both nucleons and heavy mesons, as has been suggested by one of us.[13]

While the first alternative for resolving the

[13] K. Greisen, Phys. Rev. 73, 521 (1948).

contradiction may seem more easily digestible, it meets with difficulty in accounting for the experimental results of Cocconi,[7] Janossy, and Broadbent,[8] and Salvini and Tagliaferri,[9] who found that the number of penetrating particles in extensive air showers, recorded under absorbers of different atomic number, was independent of Z. As has been pointed out by Ferretti,[14] this would imply a cross section for meson production proportional to Z^2.

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The authors wish to thank Professor H. A. Bethe and especially Dr. G. Cocconi for helpful discussions of the problems associated with air showers. They are grateful to Professors B. E. Cohn and M. Iona of Denver University for assistance in the arrangements for performing the experiment, and to the cosmic-ray group of M.I.T. for the supply of electrical power on Mt. Evans.

The work here reported was in part supported by the Office of Naval Research.

PHYSICAL REVIEW VOLUME 74, NUMBER 4 AUGUST 15, 1948

The Beta- and Gamma-Spectra of Gallium Irradiated by Slow Neutrons*

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(Received April 28, 1948)

The beta- and gamma-ray spectra of gallium irradiated with slow neutrons have been investigated with a thin-magnetic-lens spectrometer. Probable beta-ray end points for Ga^{72} at 3.15 Mev (9.5 percent), 2.52 Mev (8 percent), 1.48 Mev (10.5 percent), 0.955 Mev (32 percent), and 0.64 Mev (40 percent) were found. A conversion line occurring in about 0.5 percent of the disintegrations was observed at 0.68 Mev. Gamma-rays of 2.51 Mev (26.5 percent), 2.21 Mev (33 percent), 1.87 Mev (7.8 percent), 1.59 Mev (4.5 percent), 1.05 Mev (4.5 percent), 0.84 Mev (100 percent), and 0.63 Mev (24 percent) were also found for Ga^{72}. A nearly complete decay scheme for Ga^{72} is suggested.

The beta-ray spectrum of Ga^{70} (20.5 min.) has also been observed with the spectrometer. The Kurie plot is linear from the end point of 1.65 Mev to 0.4 Mev. No evidence of conversion lines in this energy interval was found.

I. INTRODUCTION, Ga^{72}

In 1935 Amaldi *et al.*[1] reported a 23-hour strong gamma-ray activity in gallium irradiated with a slow neutrons. Chemical identification, assignment of the activity to Ga^{72}, and accurate measurement of the half-life (14.1 hr) were accomplished by Sagane[2] who observed hard beta-radiation as well as the hard gamma-radiation. This isotope has also been produced by Ga(d,p),[3] Ge(n,p),[4] Ge(d,α)[4] and by decay of the uranium fission product Zn^{72}.[5]

The maximum end point of the beta-ray spectrum was first reported to be 1.71 Mev by Sagane *et al.*[6] using a cloud chamber. Livingood and Seaborg,[7] using absorption methods, later reported an end point at 2.6 Mev. Siegel and Glendenin,[5] using absorption in Al, reported two groups of beta-rays with end points of 3.1 Mev (35 percent) and 0.8 Mev (65 percent) while Mitchell *et al.*[8] by the same method found 2.3 Mev and 0.77 Mev. In a preliminary report[9] on the present work in which a lens spectrometer was used, the author reported five apparent end points, 3.15 Mev (9.5 percent), 2.52 Mev (8 percent), 1.48 Mev (10.5 percent), 0.95 Mev

* All of the experimental work and a major portion of the analysis for this paper was performed under Contract W35-058 Eng 71 with the Atomic Energy Commission.

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