Narrow Air Showers of Cosmic Rays II. Absorption Measurements*

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The absorption of narrow air showers in Pb, Fe, and Al has been measured at sea level. Results indicate that there are two components in these narrow air showers, a soft component which consists of electrons and a hard component which consists of μ-mesons. The soft component is practically completely absorbed in four inches of lead, whereas the hard component is not appreciably absorbed in $8\frac{1}{2}$ inches of lead. A wooden roof of only 1 g cm^{-2} produces many local showers, which are nevertheless totally absorbed in a very thin layer of material.

I. INTRODUCTION

In a previous paper,[1] it was pointed out that the penetrating power of narrow air showers observed at Climax, Colorado, at 3510 meters elevation, was higher than that of extensive air showers. Similar results have been obtained by Alichanian and Shostokovich.[2] A satisfactory interpretation of the nature of the particles in these narrow air showers was not obtained, however, in either investigation. To increase the precision of the measurements, the absorption of narrow air showers has been measured again in the Sloane Physics Laboratory at Yale University, near sea level, with an improved experimental arrangement. The data obtained have much smaller statistical errors than those found previously, and the picture of the nature of particles in narrow air showers is consequently clarified.

II. EXPERIMENTAL ARRANGEMENT

The arrangement of counters and absorbers is shown in Fig. 1. Two groups of counters, A and B, each consisting of five counters in parallel were put at a distance of 30 cm from center to center. Together with another pair of single counters D and E, they were placed above a 2-inch thick pile of lead blocks and were shielded on the sides by 6 inches of lead. The counters were covered with different thicknesses of Al, Fe, or Pb. Two meters from the center of A and B there was a group of ten counters, C, which was not shielded. Cathode followers were built into the counter trays, from which pulses were applied to the coincidence circuits by cables; in trays C, besides the cathode followers, a diode mixer was used to reduce the capacitive load of the counters.

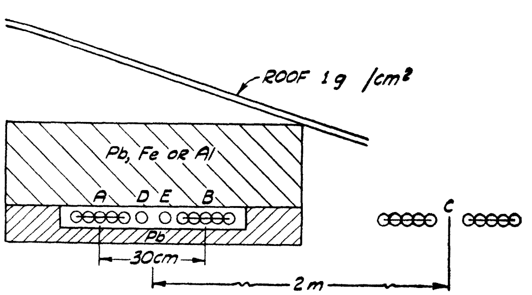

FIG. 1. Arrangement of counters and absorbers.

All counters were of the same dimensions and were filled with an argon-ethyl-ether mixture. They had a starting voltage of about 700 volts and a plateau of about 600 volts. The counters had glass envelopes 0.5 mm thick and an inner diameter of 3.2 cm. The active area of each was 60 cm^2. A thin coating of Aquadag inside the glass wall served as the cathode. The operating voltage used was 1000 volts.

Coincidence circuits were of the conventional Rossi type. The resolving time, τ, of the twofold coincidence circuit AB was measured by equating the rate of accidental coincidences to $2A\cdot B\tau$, from which τ was found to be 1.7 microseconds.

Both counters and circuits were housed in a penthouse built on the roof of the laboratory, at 42 meters above sea level. The penthouse had a thin wooden roof of $\frac{3}{4}$ inch, or about 1 g cm^{-2}.

III. DATA

The experiment consisted in the measurement of the absorption of both narrow and extensive air showers and the effect of the roof in producing local showers.

In the absorption measurement, the coincidence rates AB, ABC, $ABDE$, and $ACDE$ were all recorded simultaneously with different thicknesses of absorbers. A maximum thickness of 9 inches of Al, $8\frac{1}{4}$ inches of Fe, or $8\frac{1}{2}$ inches of Pb was used.

The twofold coincidence AB represented the total shower rate of narrow and extensive showers. Single rates of A and B were measured daily and were used to compute the accidental correction for the AB coincidence rate. No correction for other coincidences was needed, accidentals being negligible.

The difference of the total and the extensive shower rates, AB–ABC, was used as the narrow shower rate, both air showers and local showers. It will be shown that it is easy to eliminate the local showers, leaving only narrow air showers. Note also that this method of taking the difference is essentially an anticoincidence

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[1] J. Wei and C. G. Montgomery, Phys. Rev. **76**, 1488 (1949).
[2] A. Alichanian and N. Shostokovich, J. Phys. USSR **10**, 518 (1946).

TABLE I. Shower rates under different thicknesses of absorber.

Absorber	inches	rad. lengths	AB	ABC	$ABDE$	$ACDE$	Total time minutes	Narrow sh. rate, min.$^{-1}$	Ext. sh. rate, min.$^{-1}$	Dense narrow shower rate, min.$^{-1}$
				Number of coincidences						
Al	0	0	5350	243	327	58	2750	1.826±0.026	0.088 ±0.006	0.098±0.005
	3/8	0.10	4533	308	566	60	4214	0.973±0.015	0.073 ±0.004	0.120±0.005
	3/4	0.19	39538	2781	5912	596	37492	0.953±0.005	0.074 ±0.001	0.142±0.002
	1½	0.39	1594	120	259	31	1392	1.032±0.028	0.086 ±0.008	0.164±0.010
	3	0.78	6581	435	1106	102	5316	1.134±0.014	0.082 ±0.004	0.189±0.006
	6	1.55	2179	106	392	27	1836	1.101±0.026	0.058 ±0.006	0.199±0.010
	9	2.32	12435	588	2519	297	11132	1.042±0.010	0.053 ±0.002	0.200±0.004
Fe	¼	0.35	1733	126	265	20	1440	1.093±0.027	0.088 ±0.008	0.170±0.011
	¾	1.04	1450	108	246	33	1134	1.157±0.032	0.095 ±0.009	0.188±0.013
	1¼	1.73	5288	304	912	80	4250	1.151±0.017	0.072 ±0.004	0.196±0.007
	1¾	2.42	3287	193	628	68	2837	1.070±0.019	0.068 ±0.005	0.197±0.008
	2¼	3.11	1720	88	351	30	1605	0.996±0.025	0.055 ±0.006	0.200±0.011
	3¼	4.49	2575	117	508	40	2920	0.821±0.017	0.040 ±0.004	0.160±0.007
	4¼	5.87	2170	90	483	33	2865	0.706±0.015	0.031 ±0.003	0.157±0.007
	5¼	7.25	2780	92	615	34	4330	0.602±0.012	0.021 ±0.002	0.134±0.006
	6¼	8.63	6800	217	1640	97	11645	0.547±0.007	0.017 ±0.001	0.133±0.003
	8¼	11.4	2894	51	733	20	5363	0.512±0.010	0.010 ±0.001	0.133±0.005
Pb	¼	1.6	2029	119	324	29	1420	1.321±0.031	0.088 ±0.008	0.208±0.012
	½	2.8	1775	128	337	44	1455	1.111±0.029	0.088 ±0.008	0.201±0.012
	1	5.2	5236	332	1045	116	5305	0.903±0.013	0.063 ±0.004	0.175±0.005
	1¼	6.4	7345	415	592		8605	0.780±0.009	0.048 ±0.002	
	1½	7.6	5105	291	1177	94	7240	0.685±0.010	0.040 ±0.002	0.150±0.005
	2	10.0	2541	95	604	25	4245	0.553±0.012	0.0224±0.002	0.136±0.006
	2½	12.5	5308	163	1303		10121	0.487±0.007	0.0163±0.001	
	3	14.8	5417	112	1342	42	11170	0.457±0.006	0.0100±0.001	0.116±0.003
	4	19.7	5666	63	1502	63	12972	0.415±0.006	0.0040±0.0005	0.111±0.003
	5	24.5	2552	11	704	3	5740	0.425±0.009	0.0019±0.0006	0.122±0.004
	6½	31.7	2620	11	681	6	6005	0.418±0.008	0.0018±0.0006	0.112±0.004
	8½	41.4	4206	10	1092	9	9762	0.412±0.006	0.0010±0.0003	0.111±0.004

method; although it needs more circuits, it gives more information than the conventional method.

All data concerning the rates of narrow air showers under different thicknesses of absorbers are given in Table I. The thickness of lead in radiation lengths given in this table includes also a ¼-inch iron plate on which the weight of the lead blocks was supported. Errors given are standard deviations.

The fourfold coincidences $ABDE$ and $ACDE$ are also included in the same table. Their difference gives the rate of dense narrow showers which will be of use in later discussions. Note that four rays are needed for either coincidence. In fact, only showers containing many more than four rays were recorded because the areas of both D and E were much smaller than A or B.

The absorption of narrow showers under small thicknesses of iron was measured both inside the penthouse and outside, on top of the roof in open air. The data obtained are given in Tables II and III.

IV. RESULTS AND DISCUSSION

The results on the absorption of narrow air showers are plotted in Fig. 2. The abscissa is the thickness of the absorber in radiation lengths. The maximum thickness of lead, iron, and aluminum is about the same in inches, but very different in radiation lengths.

Beyond 20 radiation lengths of lead, the absorption curve is a horizontal line. This indicates the existence of a hard component which is not appreciably absorbed by many inches of lead. This component probably consists of μ-mesons because of this great penetrating power.

For less than 20 radiation lengths of lead, the absorption curve shows the existence of less penetrating particles. The amount of iron used is just about enough to absorb most of this component. If it be assumed that the absorption curve of iron will eventually coincide with the absorption curve of narrow showers in lead when more iron absorbers are used, the same value of the hard component of narrow air showers can be subtracted from both the lead and iron curves in the region of less than 20 radiation lengths and the two absorption curves thus obtained will be the absorption curves for the soft component alone. This procedure implies that the penetrating component of narrow air showers is present in the air and not produced in the absorber. They are plotted in Fig. 3. The amount of aluminum used is not sufficient to allow such a treatment of the observations. However, it does show that the same type of absorption curve may be obtained.

For comparison the absorption curve of extensive air showers in lead is plotted in the same graph. On a semilogarithmic plot, all three are straight lines in the range discussed, and all have the same slope. This indicates that the soft component of narrow air showers must consist of the same kind of particles as in extensive air showers, namely electrons. Furthermore, this

TABLE II. Narrow showers under thin thicknesses of absorber inside penthouse.

Absorber (g/cm²)	Narrow (min.⁻¹)	Extensive (min.⁻¹)	Dense narrow (min.⁻¹)
0	1.876±0.044	0.088±0.009	0.103±0.010
0.62	1.295±0.033	0.087±0.008	0.133±0.010
1.24	1.152±0.027	0.082±0.008	0.140±0.009
1.86	1.094±0.033	0.095±0.010	0.159±0.012
2.48	1.067±0.017	0.079±0.004	0.154±0.006
3.72	1.122±0.020	0.089±0.006	0.159±0.007
4.96	1.185±0.031	0.096±0.007	0.162±0.009

TABLE III. Narrow showers under thin thicknesses of absorber in open air.

Absorber (g/cm²)	Narrow (min.⁻¹)	Extensive (min.⁻¹)
0	1.132±0.029	0.067±0.007
0.7	1.088±0.028	0.078±0.008
1.34	1.099±0.028	0.089±0.008
1.96	1.051±0.026	0.057±0.006
2.58	1.097±0.028	0.082±0.007
5.68	1.324±0.031	0.098±0.008

also shows that this soft component loses energy by radiation, which is a strong evidence of electrons.

In Fig. 2 points from the absorption of narrow air showers taken at Climax are also plotted. Comparison of these two experiments is difficult since both the arrangements of counters and the precision of points obtained are different.

For very small thicknesses of absorbers, a sharp decrease in shower rates is observed. This is attributed to the recording of local showers produced in the roof above. Almost half the showers recorded are locally produced when there is no absorber used. Fortunately these local showers are so soft that they do not penetrate any considerable thickness of the absorbers used. Therefore the result of our experiment is not interfered with because of the existence of such local showers, although the number is large.

This point is clarified by comparing also the absorption of narrow showers inside and outside the penthouse. Data are given in Tables II and III and in Fig. 4. Curve *I* is actually the beginning part of the curves in Fig. 2 with more points and on a different scale. The narrow-shower rate decreases to a minimum at about 2 g cm^{-2} and rises again for larger thicknesses of absorber. In open air (Curve *II*) the shower rate at zero thickness is about the same as that at 2 g cm^{-2}. The higher value at zero absorber thickness inside the penthouse is interpreted as the result of local showers.

Since the values of the shower rate inside and outside are the same at 2 g cm^{-2}, local showers produced in the roof must be practically all absorbed in about that thickness of iron. That corresponds to the penetration of electrons of several Mev of energy. The flat part of the absorption curve from zero to 2 g cm^{-2} in open air shows that there are also some very soft narrow air showers. These might have been produced in the same manner in air as are the local showers in the roof.

Local showers are produced in the roof probably either by the pair production of photons in the roof, or by knock-on electrons. Because there is a minimum in the absorption of photons in air[3] at some tens of Mev, a great number of photons in that energy range must exist at sea level. The roof shifts the minimum towards the lower energy side and thus pairs are produced. Because of the large number of photons in that energy range, there is a considerable number of pairs produced in spite of the low probability of pair production in such a thin roof.

These local showers could also be mesons accompanied by their knock-on electrons. Since the number of knock-ons decreases rapidly with energy[4] most of them are readily absorbed by thin layers of material.

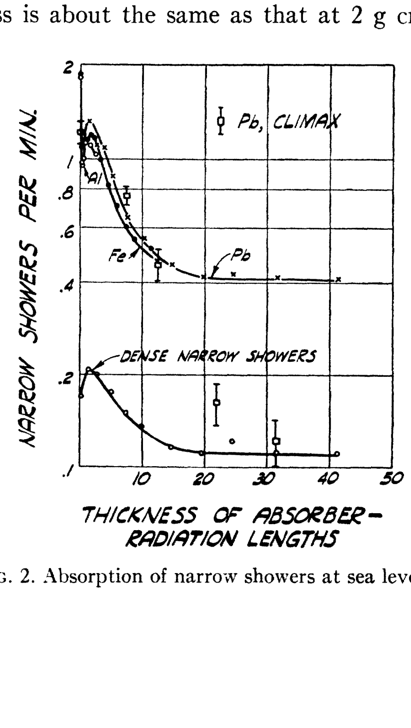

FIG. 2. Absorption of narrow showers at sea level.

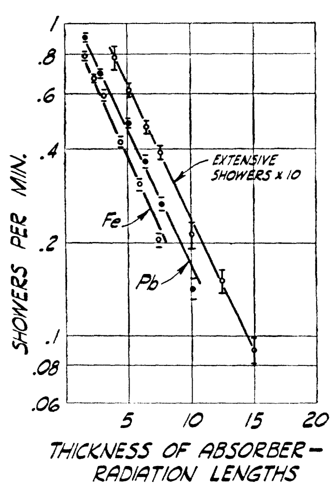

FIG. 3. Absorption of the soft component of narrow air showers.

[3] B. Rossi and K. Greisen, Rev. Mod. Phys. **13**, 263 (1941).
[4] H. J. Bhabha, Proc. Roy. Soc. **A164**, 257 (1938); F. L. Hereford, Phys. Rev. **75**, 923 (1949).

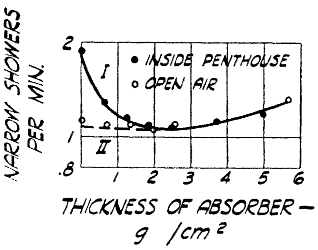

FIG. 4. Absorption of narrow showers under small thicknesses of absorbers.

Data on the number of dense narrow air showers will also support this interpretation. The fact that the absorption curve of showers recorded by *ABDE–ACDE* is parallel to that of the total narrow air showers shows that the former is a part of the narrow air showers recorded by *AB–ABC*. About one-fourth of the total number of narrow air showers are dense ones. At small absorber thicknesses, with the counters inside the penthouse, the dense narrow shower rate decreases continually with the decrease of absorber down to zero thickness. The absence of an increase near zero thickness shows that there is no appreciable number of local showers with four rays or more to produce an *ABDE* coincidence. This agrees with the assumption that they are pairs.

The fact that *ABDE* is much smaller than *AB* proves that the latter is not due to the counting of horizontal single rays, because if it were, *AB* and *ABDE* should be equal. Also, counters are shielded from the sides with 6 inches of lead at all times; the fact that *ABDE* varies with absorbers at top also indicates that the particles do not come through the sides. Furthermore, a test was made by putting one counter directly over *D* just out of line of the rest of the counters. The result obtained indicates that if there were any single rays counted as narrow showers, the number must be smaller than 3 percent of the total shower counts.

The absorption of extensive air showers has been widely studied. The discrepancies among the results of different authors have been pointed out by Auger *et al.*[5]

[5] Auger, Daudin, Freon, and Maze, Comptes Rendus **228**, 178 (1949).

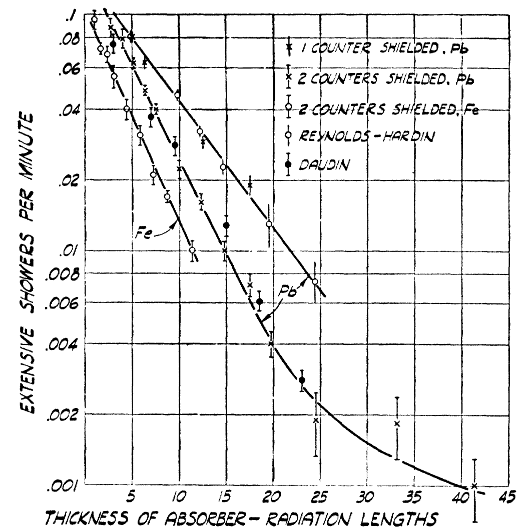

FIG. 5. Absorption of extensive air showers in Pb and Fe.

as being a result of the use of different numbers of counters shielded in lead. They found that results obtained by different authors with the same number of shielded counter trays agreed very well. This is shown also in Fig. 5 by the comparison of data obtained here with those obtained by Reynolds and Hardin[6] for one shielded counter, and that obtained by Daudin[7] for two shielded counters. The absorption curve of extensive air showers in iron is also given in Fig. 5. It is parallel to the lead curve having the same mean free path of 5 radiation lengths. The hard component of extensive air showers is shown by the bend at large thicknesses.

In conclusion the author wishes to express his gratitude to Professor C. G. Montgomery for his continuing interest and guidance throughout the course of these experiments.

[6] G. T. Reynolds and W. D. Hardin, Phys. Rev. **74**, 1549 (1948).

[7] J. Daudin, Cosmic Radiation (Interscience Publishers, Inc., New York, 1949), p. 165.