viz., to the so-called electronic residuals. Such an explanation is, however, subject to grave doubt because these residual radiations form but a few percent of the total. The experiments referred to were carried out at about the same latitude as ours but at an altitude of about 200 m above sea level. At this altitude the intensity of the residuals in vertical direction is but 5 percent of the total intensity and is even less in directions inclined to the zenith. Furthermore, the effect observed did not change sensibly with change in altitude, i.e., with change in magnitude of the residual component. At 2500 m the above authors report a deviation from the $\cos^2\theta$ law of the same order as at 200 m.

In conclusion our measurement both with lead absorbers and with varying zenith angle on the intensity variation of the mesonic component of cosmic radiation does not confirm the existence of fine structure in the absorption curves.

PHYSICAL REVIEW VOLUME 70, NUMBERS 11 AND 12 DECEMBER 1 AND 15, 1946

Penetrating Particles in Air Showers

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(Received May 4, 1945)

The paper describes some experiments performed at 2200 meters above sea level for the purpose of investigating the nature of the particles which form the extensive cosmic-ray showers in air. The results show that these showers contain both electrons and mesons.

1

In the study of extensive air showers the question of the role played by penetrating particles (mesons) is an important one.

Since air showers were first discovered, coincidences were observed with one of the G-M counters surrounded by lead shields of a thickness greater than an electron can penetrate.[1]

Later, experiments by Wataghin, De Souza, and Pompeia[2] revealed the existence of showers of considerable extent, containing at least two penetrating particles. These experiments were performed with G-M counters in coincidence, all appropriately shielded and placed in a horizontal plane, at distances varying from 35 to 120 cm.

However, the above experiments had only a qualitative value because the number of coincidences observed was of the same order as the number of chance coincidences. Moreover, they did not establish clearly the relation between penetrating showers and ordinary electron showers.

The existence of air showers containing several mesons, generated by a multiplication process closely related to that responsible for the production of ordinary air showers, was revealed by the writers in 1942.[3] Subsequently we were

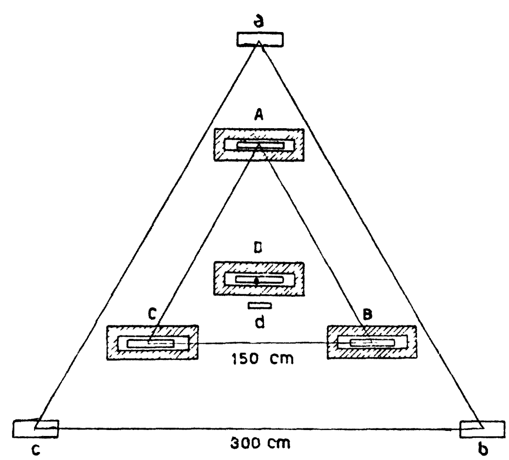

FIG. 1. Counter arrangement.

[1] P. Auger, R. Maze, P. Ehrenfest and A. Freon, J. de Phys. et Rad. **10**, 39 (1939).

[2] G. Wataghin, N. D. De Souza Santos, and S. A. Pompeia, Phys. Rev. **57**, 61 (1940); **59**, 902 (1941).

[3] G. Cocconi, A. Loverdo and V. Tongiorgi, Naturwiss. **31**, 135 (1943).

able to show that the majority of the meson showers are accompanied by electron showers containing a large number of particles.

2

Experiments on the meson showers were repeated in the summer of 1943 at Passo Sella (2200 m above sea level), with an experimental arrangement designed to furnish more detailed information on the phenomenon.

With two independent circuits, we recorded threefold ($T_h=A+B+C$) and fourfold ($Q_h=A+B+C+D$) coincidences between heavily shielded counters. These counters were placed at the vertices and at the center of an equilateral triangle of 150-cm sides (see Fig. 1). In this way one could be sure that the coincidences were produced by extensive showers, of 3 or 4 particles at least, capable of penetrating the absorber.

With another similar arrangement, we also recorded threefold ($T_s=a+b+c$) and fourfold ($Q_s=a+b+c+d$) coincidences between unshielded counters placed as indicated in Fig. 1, so as to detect ordinary electron showers.

Finally, with two circuits T_s+T_h and T_h+Q_s (see Fig. 2) we also recorded coincidences between showers of penetrating particles (T_h) and ordinary electron showers (T_s and Q_s).

From the numbers of coincidences T_h and Q_h we obtain information on the density Δ_h of penetrating particles (mesons); while from the numbers of coincidences T_h+Q_s and T_h+T_s we obtain information on the density of electrons Δ_{h+s} which accompany the meson showers.

To make sure that the observed particles were

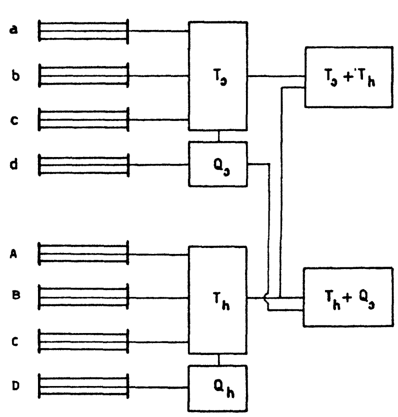

FIG. 2. Arrangement for the recording of coincidences.

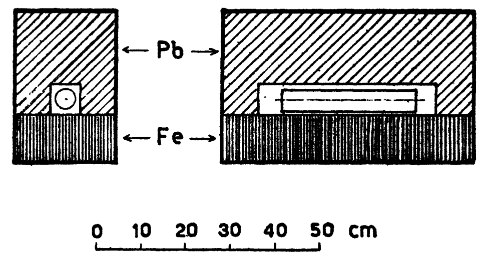

FIG. 3. Arrangement of the shield around the counters.

mesons, counters A, B, C, and D were shielded at the bottom by an iron plate 10 cm thick, at the top by a lead absorber not less than 16 cm thick, and on the sides by lead walls not less than 8 cm thick, as shown in Fig. 3.

Increasing the thickness of the upper absorber from 16 to 24 cm, and that of one of the side walls from 8 to 16 cm, failed to produce any appreciable variation in the number of coincidences per minute. This confirms the assumption that the observed particles are mesons.

The counters (a, b, c, and d) recording electron showers were placed immediately under the roof (which had a thickness of 4 g/cm^2) in order to minimize the effect of multiplication in the material of the roof.[4] The shielded counters were placed on the floor.

All the counters had brass walls, were filled with an argon-alcohol mixture, and had a threshold of about 1300 volts. They were kept at a temperature of about 15°C by thermostatic control. The resolving time of the coincidence circuits was approximately 3×10^{-7} minutes. The number of threefold chance coincidences, in the most unfavorable conditions was less than 3 percent of the number of true coincidences and was, therefore, negligible.

The measurements were carried out uninterruptedly day and night for a period of 100 days The operation of the counters and of the circuits was checked daily. Special care was taken to guard against spurious counts by grounding the counters, the circuits, and the cables. The absence of disturbances was checked every 3 or 4 days by test runs with the counter voltage below threshold. These checks were particularly desirable on account of the very small number of true coincidences.

[4] G. Cocconi, A. Loverdo, and V. Tongiorgi, Nuovo Cimento **1**, 314 (1943); Phys. Rev. **70**, 841 (1946).

TABLE I. Summary of experimental results.

Counter area (m^2)	Minutes	T_h	Q_h	Δ_h (m^{-2})	T_h+T_s	T_h+Q_s	Δ_{h+s} (m^{-2})
0.0129	66,016	$34=5.2\pm0.9\times10^{-4}$ min.$^{-1}$	$19=2.9\pm0.7\times10^{-4}$ min.$^{-1}$	64 ± 22	34	27	800 ± 400
0.0258	31,271	$32=10.2\pm1.8\times10^{-4}$ min.$^{-1}$	$23=7.4\pm1.5\times10^{-4}$ min.$^{-1}$	49 ± 21	32	23	600 ± 300

3

In order to obtain quantitative information on the density distribution of the meson showers, shielded counters with three different areas were used, namely $S_1=0.0258m^2$, $S_2=0.0129m^2$, $S_3=0.0027m^2$. As explained elsewhere,[4] by changing the sensitive area of the counters one explores different "bands" of the density spectrum of showers.

The arrangement for the detection of electron showers had to satisfy two conditions: (1) have a high efficiency, in order to detect most of the electron showers associated with meson showers and (2) furnish quantitative information on the density of showers with large numbers of particles.

The first purpose was achieved by using large counters ($S=0.0258m^2$) in the threefold coincidence arrangement ($T_s=a+b+c$). The second purpose was achieved by selecting as fourth counter in the fourfold coincidence arrangement ($Q_s=a+b+c+d$) one with small area ($S=0.0020m^2$).

The experimental results, which are summarized in Table I, confirm our previous conclusions. Out of a total of 74 meson showers recorded, only 8 were not accompanied by a coincidence in the counters detecting electron showers. In order to explain this result, one as to assume that the average density of particles in the electron showers associated with meson showers is larger than 150–200 m^{-2}.

The densities Δ were determined from the equation

$$\Delta=\frac{1}{S}\log\frac{T}{T-Q}.$$

It appears from the table that the density Δ_h of meson showers is a function of S. The same has been shown to be true for electron showers.[4] It may be noted here that no counts were recorded in 20,000 minutes using shielded counters with sensitive areas $S=0.0027m^2$.

Comparison with previous results[4] shows that meson showers are about 300 times less frequent than electron showers of the same density; i.e., recorded with counters of the same area S. If this holds true for all values of S, it explains the failure of recording any count with shielded counters of $0.0027m^2$ area (the expected number of counts turns out to be one every 25,000 minutes!).

The average density Δ_{h+s} of electron showers associated with meson showers has also been determined and has a value between 600 and 800 particles/m^2.

The above results, although necessarily inaccurate, throw some light on the nature of extensive air showers. In fact, the number of meson showers of density $\Delta_h\approx50m^{-2}$ which give rise to threefold coincidences is 10^{-3} per minute. Since the efficiency of our experimental arrangement may be estimated to be about 0.4, the absolute number of the above showers turns out to be approximately 3×10^{-3} per minute.

From the distribution formula for electron showers established elsewhere[4]

$$\nu(\Delta)=80\Delta^{-2.6}\ \mathrm{min}^{-1},$$

one calculates a number of 2×10^{-3} showers per minute with $\Delta>600$ particles per m^2. Even considering the large statistical errors, one can hardly escape the conclusion that *the majority if not all of the electron showers are accompanied by meson showers.*

This conclusion, along with that reached previously, to the effect that all meson showers are accompanied by electron showers, shows in our opinion that *in the multiplication process which gives rise to large air showers, not only electrons, but also mesons are produced.*

We wish to thank the Comitato per la Geofisica e la Meteorologia del Consiglio Nazionale delle Ricerche and the Physical Institute of the University of Milan, for financial support of this work. We also thank Professor G. Polvani for lending us experimental equipment.