On the Fine Structure of Zenithal Curves of the Cosmic Radiation

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Differential measurements of the absorption in lead of the mesonic component of cosmic radiation at 2200 m above sea level and also measurements of the variation of the mesonic component with zenith angle do not confirm the existence of a fine structure in the intensity spectrum. With zenith angle the variation is perfectly regular and roughly follows the $\cos^2\theta$ law.

It is known that the directional intensity of the cosmic radiation decreases as the inclination θ with respect to the zenith increases. This decrease may with good approximation be represented by the $\cos^2\theta$ law.

Schremp and Ribner,[1] Cooper,[2] and Schremp and Banos[3] have made measurements of the directional intensity as a function of the zenith angle at different azimuths and have observed a "fine structure" in the intensity curve. Schremp[4] inferred that a fine structure may be produced by the terrestrial magnetic field or by anomalies in the primary spectrum.

On the basis of the last hypothesis we performed an experiment during the period June–September, 1941 designed to show the possible band structure of the primary radiation by observing the spectrum of the mesonic component. It is assumed that the spectrum of mesons produced high in the atmosphere would correspond to the primary radiation which produced them and show the same irregularities.

With the apparatus indicated in Fig. 1 at 2200 m above sea level (Passo Sella, $H=7.9$ m, H_2O; geomagnetic latitude 49°N) we observed the triple coincidences among the counters A, B, C, and the quadruple coincidences $ABCD$ at the same time. Lead with thickness from 0 to 78 cm was placed at Σ_1 and Σ_2. From these observations the anticoincidences $ABC-D$ can be deduced.

The difference between the anticoincidences obtained with and without the 3 cm of lead placed at P gives the number of particles which after passing through the lead $\Sigma=\Sigma_1+\Sigma_2$ are stopped in P. This is the number of particles with energies between E and $E+\Delta E$ where E is the energy necessary to penetrate the atmosphere and the lead Σ and ΔE is the energy necessary to penetrate the 3 cm of lead at P. Thus the spectrum of the mesons with energy between 1.7 and 2.7×10^9 ev is determined directly.

Curve (a) in Fig. 1 represents the anticoincidences registered with 3 cm of Pb at P and curve (b) the anticoincidences without Pb at P. The curve $a-b$ thus represents the spectrum in this energy range and it will be observed that no significant irregularities appear to exist.

A careful discussion of this experiment is given elsewhere.[5] It is concluded that the small oscillations shown on absorption curves and in the spectrum curve for 55–60 cm of Pb must be caused by spurious effects, particularly by the action of lateral showers the effects of which will not be the same with and without the 3 cm of Pb at P.

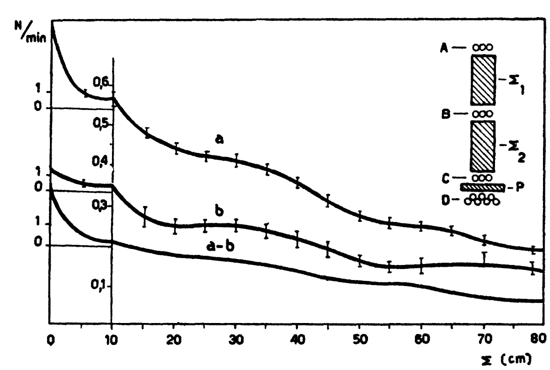

FIG. 1. Curve a: anticoincidences with 3 cm Pb in P; Curve b: anticoincidences without 3 cm Pb in P; Curve $(a-b)$: differential spectrum of vertical mesons, at 2200 m a.s.l.

[1] E. J. Schremp and H. S. Ribner, Rev. Mod. Phys. **11**, 149 (1939).
[2] D. Cooper, Phys. Rev. **58**, 288 (1940).
[3] E. J. Schremp and A. Banos, Phys. Rev. **58**, 662 (1940); **59**, 614 (1941).
[4] E. J. Schremp, Phys. Rev. **54**, 153 (1938).
[5] G. Cocconi and V. Tongiorgi, Ricerca Scient. **12**, 21 (1941).

The anomalies observed by Cooper for the zenithal angles, $\theta=7°$, $20°$, and $35°$ should be represented in our experiments by anomalies corresponding to thickness of Pb of about 35, 40, and 65 cm. The amplitudes of the oscillations observed by Cooper are calculated as two percent of the total intensity. His apparatus had a resolving power ($\rho=E/\Delta E=\cot\theta/\Delta\theta$) as large as ours. Our measurements were made under more favorable conditions for in his measurements the intensity at inclinations to the zenith would be reduced by disintegrations of mesons in the atmosphere. In our experiments the effect of the decay of mesons is small because they were carried out at considerable altitude and because the absorption took place in dense materials instead of in air.

Since the anticoincidences ($ABC-D$) are just of the order of 2 percent of the coincidences ABC the suggested oscillations should be of the same order as the anticoincidences.

We conclude, therefore, that the direct determination of the energy spectrum of mesons excludes, at least in the range from 1.7 to 2.7×10^{9} ev, the existence of anomalies which might cause a fine structure in the zenithal curves.

To aid in further clarifying these matters we decided to repeat the zenithal measurements of the authors mentioned above with an experimental arrangement equivalent to that used by one of them.[6] We felt it more desirable, however, to study the zenithal variation of only the mesonic component rather than of the total cosmic radiation. Since the soft components are in large part secondary to the hard component, particularly for directions more inclined to the zenith, it seemed desirable to make measurements only on the hard components. This has the further advantage of eliminating the effects of electronic radiations from material around the counters. These effects are difficult to check and can cause great trouble in the measurements of small intensities.

The measurements were carried out at Passo Sella continuously for 120 days during the period June–October, 1942. We used three counter telescopes, each one arranged as shown in Fig. 2 (solid angle of each telescope $5°\times16°$). Two of them were pointed SW, the third SE. The mesonic radiation was selected by 13 cm of lead. The inclination of the telescopes to the zenith were changed in steps of 5° from 0° to 60°, the inclinations being changed every five hours during the measurements. It was verified that the three telescopes in vertical orientation registered practically the same frequency of response. During the measurements, to avoid spurious effects the two telescopes in the same azimuthal orientation were kept at different zenithal inclinations. The intensity of the effect of lateral showers was determined by measuring the quadruple coincidences for each telescope when one set of counters was thrown out of alignment.

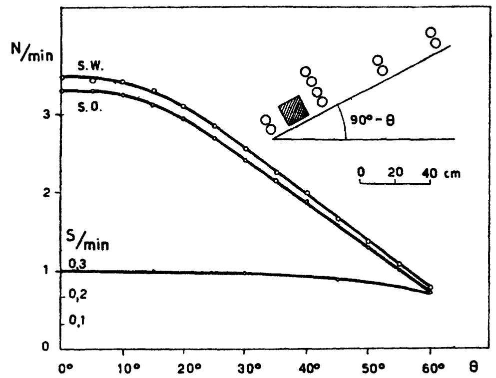

FIG. 2. Fourfold coincidences as function of zenith angle.

All counters (4.5×30 cm^{2}, filled with argon-alcohol, threshold 1300 volts, working voltage 1500 v) were electrically shielded, kept at constant temperature, and checked daily with an oscillograph.

Figure 2 shows the results of the zenithal measurements, corrected for lateral showers and the variation in intensity of the showers. It will be seen that the course of the zenithal curves is perfectly regular and follows roughly the $\cos^{2}\theta$ law although at large θ the intensity falls off more rapidly than would follow from this law. We conclude, therefore, that the mesonic component of the radiation shows no irregular variation with zenith angle.

From these measurements it would appear that the irregularities observed by the above authors must be attributed to the soft components which are not secondary to the mesons,

[6] V. Tongiorgi, Nuovo Cimento 1, 96 (1943).

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.

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Penetrating Particles in Air Showers

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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

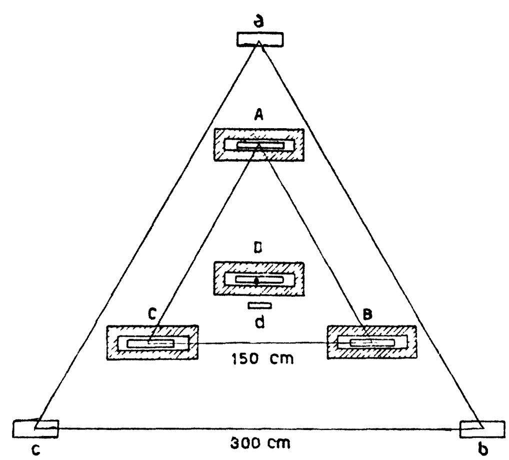

Fig. 1. Counter arrangement.

[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).