Analysis of Deep Rays

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SOFT AND HARD PARTICLES

IT is well known that the analysis of the cosmic radiation present in underground laboratories is made difficult by the strong production of secondaries, which come from the walls and roof. As, on the other hand, it is important to know the relative proportion of soft and hard particles, and if possible, their space distribution, we have tried to use an arrangement of counters in which one of the counters was well protected against the secondaries. We have obtained with this system a much higher proportion of soft particles than we had found with the generally employed free counter arrangement.

Arrangement

We used a telescope of four counters of 1.6 cm diameter and 40 cm long. One was placed axially in a cylinder of lead and was surrounded with 5 cm lead in all directions. Only a slit 2 cm wide was cut in the direction of the other counters (Fig. 1). The slit could be filled with a piece of lead, which represented the screen for the absorption of soft rays. All the system could be rotated between the vertical and horizontal directions of the plane of the counters.

Results

The system was used in underground laboratory, under 30 m of soil. We estimate that the atmosphere and rock screen is equivalent to 75 m of water. We designate this laboratory as S.75.[1]

The roof was 2 m above the apparatus. The curves (Fig. 1) give the number of coincidences for the directions making angles of 0, 30°, 60°, 90° with the vertical, for unscreened ($M+D$) and screened (D) systems. The difference between these measurements is supposed to give the value of the soft component (M). The striking feature in these results is the high proportion of soft radiation and its very broad distribution in space. (See Table I.) The background (chance coincidence) is indicated by F in Fig. 1.

[1] P. Auger, *Kernphysik* (Berlin, 1936), p. 95.

Free counter measurements

With free counters we have always obtained results indicating a very small proportion of soft radiation. In Table II, we give the results obtained with four free counters; for hard particles, we placed a lead screen 10 cm thick between two counters. We think that in this case, the absorption by the screen and the shower production are compensating each other. We could show that screens placed laterally did in fact increase the counting rate. So we think that the real value of the soft component is near that indicated by the experiment described above, but that it does not have a higher value. It gives probably the value of the soft component in equilibrium with the hard particles in lead.

SHOWERS

New measurements of the Rossi curves for two- and three-ray showers are given for two laboratories, 30 and 75 m water.

Results

With three counters we measured showers containing more than two rays, of small angle (mean angle =25°) and with four counters, those

TABLE I. *Ratio of soft component (M) and of component received in screened systems (D).*

Angle	0°	30°	60°	90°
M/D	20%	23%	39%	?

TABLE II. *Results obtained in laboratories at various depths.*

LABORATORIES	S.10	S.30	S.75	$\mu/\rho\cdot10^3$ BET. 10 AND 30	$\mu/\rho\cdot10^3$ BET. 30 AND 75
$M+D$	145	26.0	9.7		
D	121	24.3	9.4	0.80	0.21
2-ray showers					
air	30	5.9	4.9		
lead	79	26.2	11.2	0.55	0.19
3-ray showers					
air	1.6	1.0	0.4		
lead	14.9	8.3	5.0	0.29	0.11

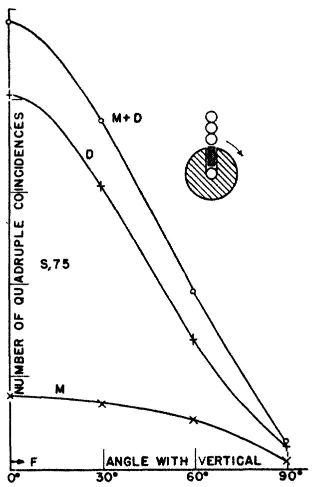

FIG. 1. Arrangement of counters. Results in underground laboratory.

containing more than three rays, the total angle being about 50°. We obtained curves of Fig. 2 for lead screen and curves of Fig. 3 for aluminum

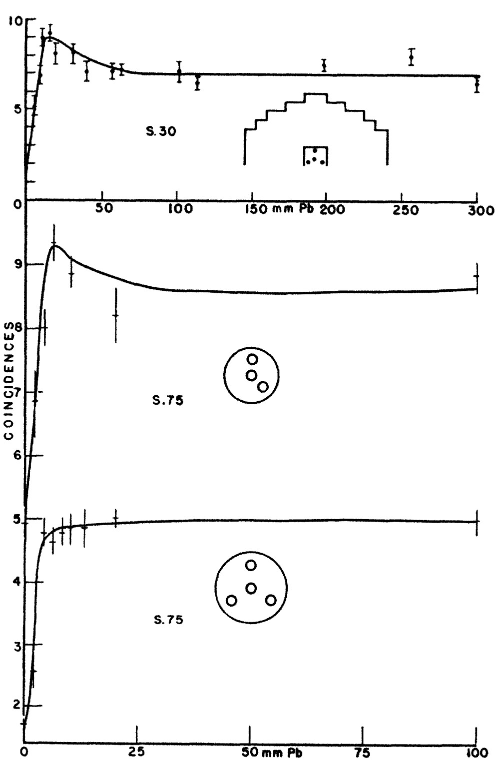

FIG. 2. Coincidences with Pb screen in two laboratories below ground.

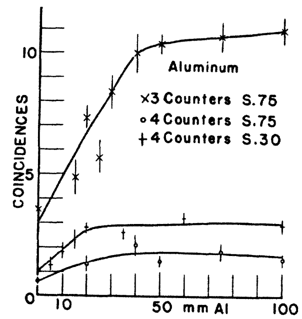

FIG. 3. Coincidences with Al screen in laboratories below ground.

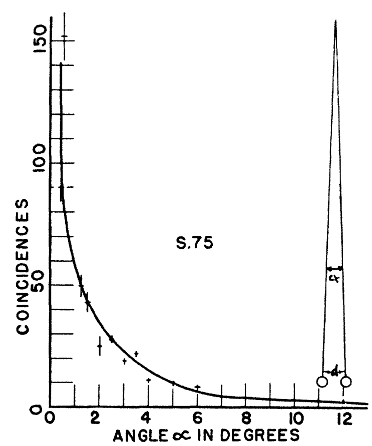

FIG. 4. Decoherence under rock.

screen. They are very different from those given for sea-level measurements.[2]

The scarcely detectable maximum in the curves relative to lead can be attributed to a transition effect; it is due to the ρ and Z differences between rock and lead (cf. Jánossy[3]). In some cases, we extended the measurements with lead to a screen thickness of 300 mm, and did not notice the second maximum (observed by several authors[4]).

In all cases, saturation was already attained with a screen of less than 12 g/cm². This corresponds to a small energy. Euler and Heisenberg[5] give 7×10^7 for electrons which can cross about 10 mm of lead. It is also the critical energy calculated for the rock.

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[2] T. Grivet-Meyer, Comptes rendus **208**, 1216 (1939).

[3] Jánossy, Proc. Roy. Soc. **167**, 499 (1938).

[4] Ackemann, Hummel, Drigo, Maass, Clay and others, Schmeiser and Bothe, etc.

[5] Euler and Heisenberg, Ergebn. d. exakt. Naturwiss. **17**, 1 (1938).

Comparison

We have made a comparison between the vertical rays (free counters) and the showers (in a cylinder of 100 mm lead). (See Table II.)

We assume that the absorption follows an exponential law to find the value of the coefficient μ/ρ g^{-1} cm^2, but Table II shows that the absorption curve becomes smoother and smoother as the rays pass through the matter. We may emphasize also the increase of the proportion: 3-ray showers/hard particles with depth. V. C. Wilson[6] found comparable figures.

Angles of Rays

We investigated the mean angle between the shower rays by the separation (decoherence) of their branches with the distance.[7]

Method

Working at station S. 75, we placed two counters (the same counters have been used for all the experiments described in this paper) 200 cm under the roof. With an apparatus of high resolving power, we registered the coincidences produced by two rays coming at the same time from the rock. In varying the distance d (Fig. 4) between the counters, we measured the number of showers for different values α of the angle of rays.

[6] V. C. Wilson, Phys. Rev. **55**, 6 (1939).
[7] P. Auger and T. Grivet-Meyer, Comptes rendus **203**, 246 (1936).

Results

Figure 4 shows that more than one-half of the rays are separated by angles smaller than 2 degrees. The theoretical angle seems to be smaller but the difference may be attributed to the diffusion.

This is in perfect agreement with the experimental values given for the "air showers"[8] and proves that the showers observed in underground laboratories are cascade showers, of the same kind as the lead showers at sea level and the air showers.

Conclusion

The evaluations of energy based on the Rossi curves and on decoherence measurements agree with the most recent theoretical numbers.

We observed a large proportion of soft rays with a wide distribution, which is probably due to the numerous showers. The deep rays seem to be characterized by their rapid filtration with the depth.

[8] P. Auger, R. Maze, P. Ehrenfest, Jr. and A. Freon, J. de phys. et rad. VII, **10**, 39 (1939).