Cosmic Rays at a Depth Equivalent to 1400 Meters of Water

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VARIOUS authors[1] have studied the nature of cosmic rays under very thick layers of matter. For the same purpose we have been performing experiments in Simidu tunnel (600 m above sea level, geographic $\varphi = 36.8°N$, $\lambda = 138.9°E$, geomagnetic $\varphi = 26.6°N$) of the government railways. An observation hut was built in one of the manholes of the tunnel under a vertical thickness of about 500 m of rocks, which consists mainly of diorite, the average density being probably 2.8, thus making the depth equivalent to about 1400 m of water.

The experimental arrangements are shown in Fig. 1. We shall denote the coincidence discharge of any one Geiger-Müller counter in each of the trays *A*, *B* and *C*, respectively, as being caused by a "single ray" and that of any one counter in each of the trays *A* and *B* and any two counters in the tray *C*, respectively, as being caused by a "shower." It is thus possible that "single rays" are sometimes showers in reality. These two types of coincidences are recorded simultaneously through two separate sets of amplifiers on the same paper tape, which is moved continuously by means of a clockwork. Lead absorbers of various thickness were placed either at the position I or II on a wood support 8 cm in thickness. Measurements were carried out for 4600 hours of observation between September, 1939, and July, 1940.

The results of the experiments are shown in Fig. 2, from which we can draw the following conclusions.

(1) There exist both "single rays" and "showers" which are hard and absorbed only gradually by 30 cm Pb. The relative abundance of "showers" to "singles" is higher than that at sea level, as was observed by various authors.[1] From this abundance, geometrical conditions and the above meaning of the word "singles" as well as from the similarity in the form of the absorption curves I for "singles" and "showers" in Fig. 2, we think that a greater part of "singles" are fragments of hard showers. We come thus to the conclusion that there exists a very high proportion of hard showers at a depth of about 1400 m water equivalent. Barnóthy and Forró observed a sharp minimum of the absorption curve at 10 cm Pb, while our minimum lies within the range of statistical fluctuations.

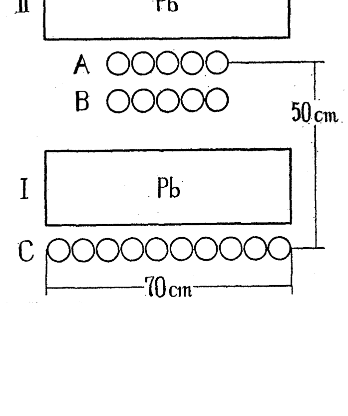

FIG. 1. Arrangement of counters.

(2) As seen from Fig. 2, the position of lead either at I or at II makes no statistically significant difference in the number of coincidences. This fact seems to show the absence of non-ionizing primary rays for the hard ionizing showers which we observe, as mentioned above, in our apparatus. It is, however, also probable that the non-ionizing rays, even if they exist, do not produce the hard secondaries within such a thin layer of matter as 20 cm Pb, because the hard showers mentioned have an average range much larger than 30 cm Pb, and these must therefore have mostly been produced within a very thick layer of rock. It is thus difficult to decide from our results whether the primaries

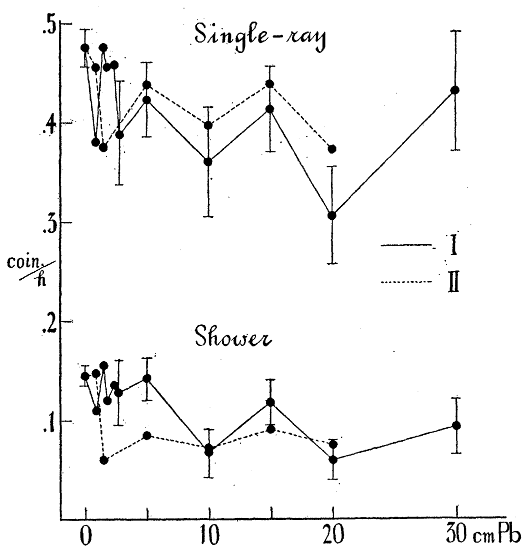

FIG. 2. Number of single rays and showers as a function of thickness of lead.

for the hard showers observed are ionizing particles such as mesons or protons,[2] or non-ionizing particles—say neutrinos—as was proposed by Barnóthy and Forró.[3]

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[1] J. Barnóthy and M. Forró, Phys Rev. **55**, 870 (1939); **58**, 844 (1940); V. C. Wilson, Phys. Rev. **55**, 6 (1939); J. Clay, Rev. Mod. Phys. **11**, 128 (1939).
[2] J. Clay, reference 1.
[3] J. Barnóthy and M. Forró, Nature **138**, 325 (1936); Zeits. f. Physik **104**, 744 (1937).