Nature of Cosmic Rays Below Ground

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IN a previous experiment,[1] cosmic-ray intensities were measured at various depths into the earth's crust. When the logarithm of the intensity was plotted against the logarithm of the depth, one straight line from 20 m to 250 m and another from 250 m to 1420 m seemed to represent the data very well. This appeared to indicate that there are two types of very penetrating cosmic rays; one with a maximum range of about 250 m, and one with a much greater range.

It was suggested by Professor A. H. Compton that experiments be performed: first, at a moderate depth (30 m) to determine the nature of the first group; and second, at a depth greater than 250 m (300 m) to determine the nature of the second group.

At 30 meters water equivalent below the top of the atmosphere two absorption curves were obtained; one with different thicknesses of lead, up to 29 cm, above a fourfold G-M tube telescope, and another with various thicknesses of lead, up to 100 cm, between the tubes of the telescope. If all the ionizing rays at this depth are penetrating rays, the two curves should be the same; but if the majority of the ionizing rays are secondaries produced by a more penetrating non-ionizing ray, the absorption should be much greater with the lead between the tubes. The two curves agree up to 29 cm of lead. Also, the absorption produced by a meter of lead is about the same as the absorption by an equivalent thickness of rock. This indicates that the majority of the rays at 30 m are penetrating ionizing rays.

A similar experiment was performed at a depth of 300 m water equivalent. Here, also, the absorption with material above the tubes was the same as the absorption with material between the tubes. Shower intensities were measured at the two depths with similar arrangements of the tubes. It was found that the shower intensity decreases less rapidly with depth than does the vertical intensity. If one assumes that the soft showers are produced by the penetrating ionizing rays, then to explain the relative increase of shower intensity with depth one may assume: (1) that there is a non-ionizing agent also producing soft showers; (2) that the more penetrating ionizing rays are more efficient in producing soft showers than are the less penetrating rays; or (3) that the character of the showers, such as angular spread, average number of particles in each shower, etc., changes with depth in such a way that the showers at greater depths have a greater probability of being recorded. By placing various thicknesses of lead between the tubes in a triangular shower arrangement it was observed that the shower particles were easily absorbed. Lead 11.4 cm thick absorbed all the shower rays, but because of the large separation of the bottom tubes this does not exclude the possibility of the existence of penetrating showers with very small angular spread.

It is concluded that at 30 m and 300 m the observable cosmic rays are penetrating ionizing rays accompanied by soft showers, which are relatively more abundant at the greater depth.

A more complete description of the above experiments is given in the *Physical Review*.[2] Earlier in this symposium Professor Clay described similar experiments, and Professor Auger will discuss the experiments which he and his collaborators have performed. There are three other similar experiments, and to make the discussions at this symposium complete, I should like to mention them.

At 70 m Nielson and Morgan[3] obtained an absorption curve with lead between a twofold G-M tube telescope. This experiment also showed the existence of penetrating ionizing rays accompanied by soft showers.

Barnóthy and Forró[4] have performed a similar experiment at 980 m depth from which they make the following conclusion, "Great depth can be attained by an ionizing radiation (most probably mesotrons or perhaps protons) and by a non-

[1] V. C. Wilson, Phys. Rev. **53**, 337 (1938).

[2] V. C. Wilson, Phys. Rev. **55**, 6 (1939).

[3] W. M. Nielson and K. Z. Morgan, Phys. Rev. **54**, 245 (1938).

[4] J. Barnóthy and M. Forró, Phys. Rev. **55**, 870 (1939).

ionizing radiation (neutrinos or neutrettos). The greater the depth, the more important the non-ionizing component becomes and at 1000 m depth it may strongly exceed the number of ionizing particles. The non-ionizing radiation produces along its path secondaries (photons, electrons) which give rise to a cascade shower."

Wataghin and Santos[5] have performed experiments to study the shower-producing radiation at depths of 50, 250, and 400 m water equivalent. Their conclusions are as follows, "At 50 m two different kinds of showers were observed: (a) showers produced by an ionizing radiation of not less than 17 cm range in lead, and (b) very soft showers produced by a non-ionizing radiation which probably are not due to a cascade process.

"In the second and third stations (250 and 400 m) the measurements have shown that the shower-producing radiation is non-ionizing and that the ionizing shower particles have a range smaller than 17 cm of lead."

[5] G. Wataghin and M. Damy de Souza Santos, Annaes da Academia Brasileira de Sciencias **11** (March 31, 1939).

It is difficult to describe a process to explain all of these experiments; however, most of the experiments indicate that there are two types of rays at great depths—one with a maximum range of about 400 meters and one with a much greater range. Professor Clay believes that the first group consists of mesotrons and the second of protons. Barnóthy and Forró[3] say that the first group consists of mesotrons, but the second group is a non-ionizing group detectable because of soft ionizing secondaries. There is still a third possibility, that is, that the first type is a non-ionizing ray and the most penetrating rays are mesotrons. The data at the present time are not sufficiently complete to enable one to decide which is the correct explanation. There may be three types of penetrating rays. Certainly more experiments should be performed to determine the nature of the penetrating rays.

Discussion

D. K. Froman, *McGill University*, and **J. C. Stearns,** *University of Denver:* It is interesting to note that the data presented by Mr. Wilson in regard to the absorption of showers agree so completely in detail with shower absorption data obtained at altitudes of 6000 and 14,000 feet, respectively.[1] Not only do the absorption curves show the same rate of absorption but they exhibit a plateau in the same region as do the ones obtained at high altitudes, and the cut-off occurs at the same thickness of lead. This is strong confirmation that the showers observed by Wilson are electron-photon showers of the cascade type.

[1] Froman and Stearns, Phys. Rev. **49**, 473 (1936); Phys. Rev. **49**, 414 (1936); Phys. Rev. **50**, 787 (1936).