A Note on the Production of Cosmic-Ray Showers

The cosmic-ray showers, which are shown so beautifully in the counter controlled cloud chamber,[1] have been investigated by numerous observers. The method in general has consisted in putting three Geiger counters below a thin plate of heavy material. The counters are usually arranged so that three particles emerging simultaneously from the plate are required to register a coincidence. Hence a shower will consist of at least three particles associated in time.

This note concerns an experiment dealing with the variation in the number of showers with depth below the top of the atmosphere. The experiment was performed in a tunnel of the Morris Dam of the City of Pasadena. Readings were taken at points where the solid angle down to 45° from the vertical was filled on all sides with a known depth of water. The coincidences were recorded with a vacuum tube circuit similar to those of Johnson and Rossi. The counters were 14 cm long and 2.5 cm in diameter. They were placed as shown in Fig. 1, beneath a lead plate 2.2 cm thick and 20×20 cm in area.

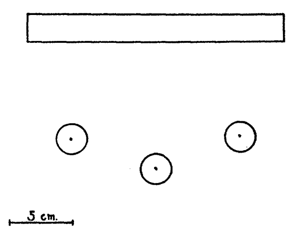

FIG. 1.

Measurements were made of the number of coincidences per hour at three locations as shown in the following table. This table gives the increase in the number of coincidences per hour due to the lead plate above the counters.

(i)	Apparatus on the top floor of Bridge Laboratory	8/hr.
(ii)	Under approx. 4 meters water equivalent below sea level	0.5/hr.
(iii)	Under approx. 10 meters water equivalent below sea level	0.1/hr.

The intensity of the vertical radiation at the three places was measured by putting the counters in a vertical line with about 6 cm between counters (i.e., 12 cm overall). Comparing this with the number of showers emerging from the 2.2 cm lead plate, one obtains,

		Vertical	Showers
(i)	At sea level	1.0	1.0
(ii)	4 meters below	0.38	0.06
(iii)	10 meters below	0.20	0.01

A few measurements have been made with varying thicknesses of lead, and these show that the thickness of lead for a maximum number of showers decreases greatly as one goes below sea level.

As a result of these experiments the following conclusions must be reached.

(i) The sea level radiation responsible for the type of coincidence here involved is softer than the average cosmic radiation.

(ii) The energy of the shower particles, as measured by the thickness of lead at which the coincidences are of maximum frequency, decreases when the shower producing radiation is filtered through water.

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I also wish to thank C. D. Anderson and R. A. Millikan for many helpful suggestions.

W. H. PICKERING

California Institute of Technology,
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[1] Anderson, Millikan, Neddermeyer and Pickering, Phys. Rev. **45**, 352 (1934).

The Thermal Equilibrium of Elementary Particles

We examine some new features of the equilibrium of matter and radiation at high temperatures $T \gtrsim 2mc^2/K$. At these temperatures the number of photons with energy $h\nu > 2mc^2$ capable of producing the creation of pairs of electrons cannot be neglected.[1] Also the collisions between the nuclei and other elementary particles, as neutrons, protons and electrons, produce the nuclear transformations in which the neutrons and protons can be captured or emitted.

We want to show that the application of the statistical laws permit the deduction from general assumptions of some properties of the elementary particles.[2]

Let us consider a region (for instance inside a star) in which nuclei, radiation and elementary particles are in thermal equilibrium. We want to assume the validity of the conservation laws of the charge, energy and momentum and of the exclusion principle for the electrons. We suppose also that it is possible to describe, at least in a first approximation, the states of the neutrons and protons by the antisymmetrical eigenfunctions and for some other particles (e.g., for photons) by symmetrical eigenfunctions.

The chief new feature of the equilibrium is that the total number of elementary particles of every kind will be variable with the temperature. The general statistical laws show, for each kind of elementary particles, the validity of the laws of Kirchhoff regarding the emission and the absorption of them by the nuclei, and the existence of a law of the spectral distribution of the number of particles among the various states which depend only on the temperature, and not on the kind of nuclei which take part in the equilibrium.

It is, for instance, noteworthy that by the usual statistical method[3] one can deduce the validity, for each kind of particles, of the asymptotical law of Wien for the density of particles with energy $W \rightarrow \infty$. Thus, from Kirchhoff's laws we conclude that the cross sections for the creation of pairs or the transformation of nuclei must tend to a constant limit when the energy of the incident particles tends to ∞.