fraction of unscattered neutrons to be detected, the effect is necessarily small.

In another scattering experiment only one plate was used and the detector was placed out of the direct beam at an angle of about twenty-five degrees so that the only neutrons counted were scattered neutrons. Again the number counted was greatest with the plate demagnetized. The percentage change was 4.1 percent ±1.4 percent. The probable error is rather large because of the high background of fast neutrons in a scattering experiment.

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[1] Powers, Beyer and Dunning, Phys. Rev. **51**, 371 (1937).
[2] Schwinger, Phys. Rev. **51**, 544 (1937).
[3] Bloch, Phys. Rev. **50**, 259 (1936).
[4] Hoffman, Livingston and Bethe, Phys. Rev. **51**, 214 (1937).

Note on the Nature of Cosmic-Ray Particles

The results of Neddermeyer and Anderson,[1] and those of Street and Stevenson,[2] seem quite clearly to indicate the presence, in the penetrating component of cosmic rays, of positive and negative particles of electronic charge, which do not radiate and make showers as do electrons, and which are not protons. Since the probability of radiation can depend essentially only on the charge and the mass of the particle, these authors suggest that we have here to do with particles of mass intermediate between that of the electron and that of the proton. If this mass μ is unique, it introduces a new constant $l=\hbar/\mu c$ into physics; and one would hope to bring this into connection with the length which plays so fundamental a part in the structure of nuclei: the "size" of the proton and neutron: the range of nuclear forces.[3] The value of some 50–100 Mev which this argument suggests for the mass of the particle seems consistent with the cloud chamber observations. These observations themselves, however, could be equally well interpreted if the particles had a quite wide variation in mass; nor do they exclude values considerably lower than 50 Mev.

In fact, it has been suggested by Yukawa[4] that the possibility of exchanging such particles of intermediate mass would offer a more natural explanation of the range and magnitude of the exchange forces between proton and neutron than the Fermi theory of the electron-neutrino field. Thus a straightforward application to this problem of the quantum theory of fields, developed for such particles by Pauli and Weisskopf, gives a Heisenberg exchange force approximately derivable from a potential of the form $-\hbar c e^{-r/l}/4\pi r$. Yet in trying to account in detail along these lines for the characteristics of nuclear forces, one meets with difficulties hardly less troublesome than in the various forms of electron-neutrino theory which have been proposed. In particular, the reconciliation of the approximate saturation character of nuclear forces with the apparent equality of like and unlike particle forces and with the magnetic moments of neutron and proton could here too be achieved only by an extreme artificiality. These considerations therefore cannot be regarded as the elements of a correct theory, nor serve as any argument whatever for the existence of the particles; their valid content can at most be this: that these particles may be emitted from nuclei when sufficient energy ($>\mu c^2$) is available, and that they will ultimately prove relevant to an understanding of nuclear forces. Since even with an energy up to 15 Mev available for the disintegration, nuclei exhibit normal β-decay, the mass of the particles must surely on this view exceed 15 Mev. These particles need not then be primary cosmic rays, but may be ejected from nuclei by γ-rays (and formed by pair production) in the upper atmosphere, and thus complicate the degradation of the primary electrons and greatly increase the effective penetration of the radiation.

The incidence near sea level of multiplicative showers may then be understood in a simple way. For on the one hand we may expect some degraded shower radiation from incident electronic primaries of high initial energy;[5] on the other hand the penetrating particles will produce electronic secondaries by extranuclear impacts; from the curvature distribution of the particles, and with any acceptably low value for their mass, one can see that impacts in which the secondary has energy enough to initiate a small shower should occur about once in 10 m water equivalent. At great elevations (>3 km from sea level) the degraded shower radiation should play the predominant part; under considerable thicknesses of heavy absorber, at sea level, this radiation will be absorbed, and only the secondaries will contribute to the multiplicative showers. Near sea level the two contributions may be comparable in importance.

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June 1, 1937.

[1] S. Neddermeyer and C. D. Anderson, Phys. Rev. **51**, 884 (1937).
[2] J. C. Street and E. C. Stevenson, Bull. Am. Phys. Soc. **12**, 2, 13 (1937).
[3] It is true that the range of nuclear forces is roughly equal to e^2/mc^2; but the fact that it has not been possible to find in electron theory itself any satisfactory physical interpretation of this "electron radius" makes it seem likely that the interpretation of even this quantity must essentially involve the heavy particles and their structure.
[4] H. Yukawa, Proc. Phys. Math. Soc., Japan **17**, 48 (1935).
[5] The number of electrons surviving at sea level depends critically on the energy of the incident particles. For vertical incidence the number surviving per primary of energy E is

$$3\cdot 10^{-12}\times\exp\{x^{-\frac{1}{3}}\ln(50x)+9x^{\frac{2}{3}}\},$$

where $x=\frac{1}{2}\ln E/I$, and $I=75$ Mev. This is the asymptotic form for $t=27$ of Eq. (36), in Phys. Rev. **51**, 227 (1937).