are in general agreement with his data. Fig. 1 gives a logarithmic plot of the current to the collector, I_c, as a function of the incident bombarding current, I_p, for constant voltage on the collector, V_c. Fig. 2 gives a similar family with I_c and V_c as variables, and I_p as the parameter. The points were taken with 650 volt primary electron beam covering an area of 0.3 cm^2 on the target.

Fig. 1 clearly indicates that the collector current, provided it is less than 1.2 ma, is proportional to some power of the primary current; the exponent decreases from, roughly, unity at zero collector voltage, to the constant value of 0.59 above 25 volts. With similar restrictions on collector current and voltage, the family of curves in Fig. 2 is also a group of parallel straight lines. Within these regions the data can thus be expressed by the relations:

$$I_c = aI_p^n V_c^m,$$

where a, n, and m are constants for a given energy and area of the bombarding beam and activation of the surface. For the data presented, $a = 2.5 \times 10^{-3}$, $n = 0.59$, and $m = 2.23$. The consistency of the relations can be further checked by the fact that the intercepts of the curves in Fig. 1, plotted in Fig. 2, belong to the family of latter curves and *vice versa*. The intercept curve is shown in Fig. 2; the ordinate scale is shifted up 2.4 units for this curve.

As in the case of aluminum oxide, the treated borate surfaces exhibit a time lag between the incident current and the current to the collector, both when the primary current is turned on and off, and when the collector potential is turned on. All the points were taken at the maximum value of I_c with time.

Barium borate, without any treatment, exhibits anomalous emission but to a lesser extent than treated surfaces. Without treatment the current to the collector is much smaller, the build up is much slower and decay very rapid. The collector voltage must be raised to 200 volts or more to observe the anomalous character of the collector current.

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[1] L. Malter, Phys. Rev. **50**, 48 (1936 .

Experiments on the Magnetic Moment of the Neutron

In order to perform experiments in which polarized beams of neutrons are used, such as determining the sign and magnitude of the magnetic moment of the neutron, it is desirable to have as large a polarization as possible. Various types of single magnet experiments have been performed in an effort to obtain larger effects. As pointed out before,[1] these experiments with a single magnet eliminate difficulties due to adiabatic transitions when the neutrons pass through regions where angular velocity of the changing magnetic field is of the same order of magnitude as the Larmor frequency, $g\mu H/h$, of the neutron.

The experiments[1] involving the transmission of neutrons through three 0.65 cm iron plates magnetized to saturation and then demagnetized have been repeated using neutrons which were emitted from an "howitzer" cooled to approximately the temperature of liquid air. Both experiments were then performed using two plates instead of three. The experimental set-up was identical in the two sets of measurements. The results of these four experiments are compared graphically in Fig. 1. It is seen that with three plates the magnitude of the effect (percentage increase in transmission of slow neutrons with the plates magnetized[1]) increases from 3.6 percent ± 0.6 percent to 5.3 percent ±1.0 percent. With the two plates the effects are smaller, being 1.9 percent ± 0.7 percent and 2.9 percent ± 0.7 percent, respectively.

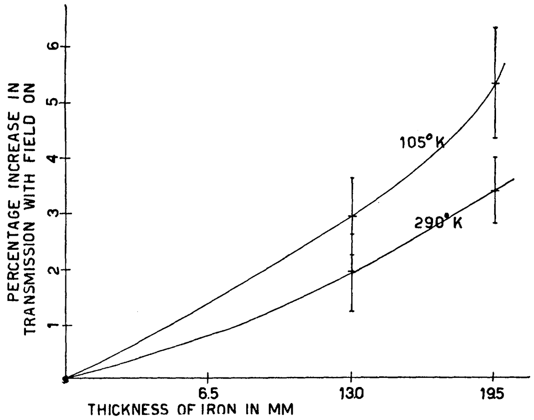

FIG. 1. Change in magnetic scattering with velocity of neutrons.

From these data it is seen that using slower neutrons increases the effect. Also greater thicknesses of iron increase the effect if multiple scattering within the iron is not excessive. However, thicknesses much beyond that corresponding to the three plates reduce the slow neutron intensity to very small values compared to the fast neutron background.

These results are consistent with theory[2-4] in that the change in scattering cross section is proportional to the form factor, $\int \exp(i(\mathbf{k}_0 - \mathbf{k}) \cdot \mathbf{r}) m(\mathbf{r}) dt$, where $\mathbf{k}_0$ and $\mathbf{k}$ are the propagation vectors of the incident and scattered neutrons, respectively; and $m(\mathbf{r})$ is the magnetization density. For slower neutrons this expression becomes larger and the percentage increase in transmission with the plates magnetized should be greater. Furthermore, within the limits of experimental error the effect varies with the square of the thickness in agreement with the theoretical prediction.[1-4]

Several attempts were made to increase the effect through collimating the neutron beam as completely as possible by various methods. No improvement in the effect was found by this method.

Several types of experiments have been performed with a single magnet in which the scattered neutrons rather than the transmitted neutrons were detected. In one, the same three plates were used; but the central portion of the beam was blocked out with cadmium. Thus the majority of the neutrons detected were scattered neutrons. As is to be expected in this case, the number of neutrons counted was less with the plates magnetized. The percentage change was 1.1 percent ± 0.5 percent. Since it was possible for a small 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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[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).