where V_0 is a real number giving the depth of the well, and ζ is a parameter which indicates an "absorption" for neutrons within nuclear matter. This absorption is introduced in order to describe the formation of the compound nucleus. The distance l in nuclear matter, within which the neutron intensity is reduced by this absorption by $(1/e)$, is given by $(\zeta K)^{-1}$. If (R/l) is small, part of the neutron wave emerges from the nucleus and causes interference with the incoming beam. If $\zeta \gg (KR)^{-1}$, no neutron wave emerges, and the results are equivalent to those of Feshbach and Weisskopf, quoted above.

The calculation of the total cross section arising from the potential of Eq. (2) is a straightforward problem of wave theory, and the results are shown in the lower half of Fig. 1 for the following choices of constants: $V_0=19$ Mev, $R=1.45\times10^{-13}A^{\frac{1}{3}}$ cm, $\zeta=0.05$. It is evident that this simple model reproduces all the main features of the experimental results. If this agreement is not fortuitous, we must conclude that in the energy range considered the neutron penetrates a distance l of about 2×10^{-12} cm into nuclear matter before it is incorporated into a collective compound motion.

It should be mentioned that the experimental curves are averaged over many narrow resonances which the simple model employed here will not predict. They are resonances of the compound system which is formed after "absorption" of the neutrons. The relatively large value of l given above does not preclude the existence of such resonances. A more elaborate theory which also includes these resonances has been developed and will be submitted for publication in the near future.

* This work was assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Miller, Adair, Bockelman, and Darden, Phys. Rev. **88**, 83 (1952); H. H. Barschall, Phys. Rev. **86**, 431 (1952).
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Direct Experimental Evidence for the Existence of a Heavy Positive V Particle*

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VARIOUS workers have shown[1,2] that some, if not all, charged V particles observed in cloud-chamber experiments can be identified with the K particles[3] (κ- and χ-mesons) found in nuclear emulsions. Direct mass measurements have been made on primary V particles of both signs of charge. These measurements have in all cases given values, somewhat lighter than a proton mass, which are entirely consistent with the known masses of K particles. The question arises, therefore, as to whether charged V particles exist whose mass is considerably greater than that of a K particle, and which perhaps decay into a nucleon and π-meson, in a manner analogous to the decay of the neutral $V_1{}^0$ particles.

Alford and Leighton[4] have suggested that the observed charged V particles may be of two or more types, of quite different lifetimes. This suggestion was based upon an observation of the distribution of the decay points of the particles in their cloud chamber. The upper chamber appeared to favor the detection of a relatively long-lived particle (i.e., $\tau\sim10^{-9}$ sec) formed in the lead blocks above the chamber, while the lower chamber seemed to show a number of particles of relatively short life ($\tau\sim10^{-10}$ sec) formed in the lead plate between the chambers.

Additional data have been obtained with the same apparatus, and an analysis has been made, based upon this apparent difference in sensitivity of the two chambers. In this way there was found a striking charge asymmetry between the charged V particles produced in the lead plate and those produced elsewhere (mainly in the lead blocks above the chamber). This is indicated in Table I.

A rough calculation reveals that, if the relative population of positive and negative V particles in the two chambers is actually the same, the statistical probability of observing the above charge asymmetry, or a greater one, is about 0.007. This result thus tends to substantiate the conclusions drawn on the basis of the distribution of the observed decay points, but it should, of course, be emphasized that the number of events is still comparatively small.

A possible interpretation of these asymmetries in terms of a mixture of long-lived and short-lived V particles might be made as follows: Because the lead blocks above the chamber are rather far away from the illuminated region, the V particles observed to decay in the upper chamber are predominantly of the long-lived type. From the charge asymmetry of this fairly pure sample of particles, we may tentatively conclude that they are produced with a negative excess of about two to one. On the other hand,

TABLE I. Classification of charged V particles according to place of origin and sign of charge.

Origin \ Sign	Positive	Negative	Total
Above plate	8	18	26
In plate	18	9	27
Total	26	27	

TABLE II. Measured data pertaining to two positive V particles with heavy charged secondary particles.

Case	Sign	P_{pri} (Mev/c)	I_{pri} (×min)	M_{pri} (m_e)	P_{sec} (Mev/c)	I_{sec} (×min)	M_{sec} (m_e)	θ	P_T (Mev/c)
1	+	–	3–7	–	360±60	3–7	1300–2300	20°	125±25
2	+	–	2–4	–	520±75	2–4	1300–2200	18°	160±40

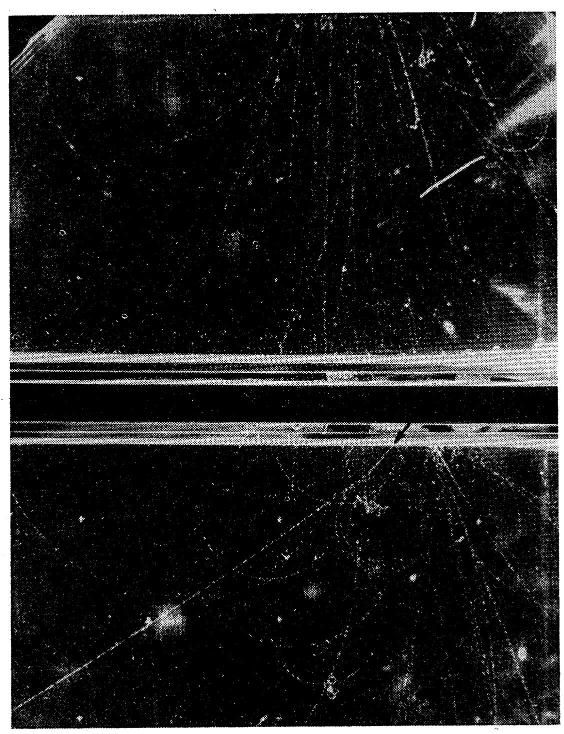

FIG. 1. Cloud-chamber photograph showing a charged V particle originating in an interaction in the lead plate and decaying into a heavy secondary particle. The V particle travels diagonally downward toward the left from the interaction and decays after having traversed only a short distance in the chamber. The heavy secondary particle proceeds almost in the same direction as the V particle. Both the primary and secondary particles are heavily ionizing.

those charged V particles originating in the plate, which is quite near the illuminated region, are a mixture of the long- and short-lived particles. From the marked positive excess of this group we may conclude that the short-lived particle is predominantly (if not always) positive.

A more direct indication that the charged V particles are composed of both (long-lived) K particles and (presumably short-lived) heavier particles is given by measurements on two positive V particles with origins in the lead plate. These proved to be of special interest because the mass of the charged secondary particle was in each case much greater than that of a π-meson. The pertinent data for these two events are contained in Table II, and a photograph of the first case is reproduced in Fig. 1. In both cases the primary track was to short to permit a momentum measurement, but is heavily ionizing. The secondary particles have masses lying in the range 1300–2300 m_e and are consistent with the mass of a proton.[5] The possibility that these events might be interpreted as the scattering of protons is ruled out by the high transverse momentum P_T of the decay and the absence of a recoil nucleus at the decay point. It is natural to suggest that this new decay follows the scheme

$$V_1^+ \rightarrow P+\pi^0+(Q\sim 40 \text{ Mev}),$$

which is a charged counterpart of the well-known neutral V particle decay scheme: $V_1^0\rightarrow P+\pi^-+(Q=35 \text{ Mev})$.[6,7] It is to be noted that the observed transverse momenta are consistent with the most probable values to be expected from this decay scheme.

One would naturally expect that an alternate mode of decay of this heavy V particle might be $V_1^+\rightarrow N+\pi^++(Q\sim 35 \text{ Mev})$, and indeed one can deduce, using the above arguments, that about 12 of the positive particles from the lead plate should be of this type. However, without accurate estimates of the masses of the primary particles it would be difficult to distinguish this type of decay from that of a K particle in any individual case.

* Supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

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Meteorites as Cosmic-Ray Meters

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THE production of helium in iron meteorites by cosmic rays[1] has been treated quantitatively in a recent publication.[2] In addition, a method was described there for separating the contributions from cosmic rays and from radioactivity (uranium and thorium) to the total helium content of the meteorite; namely, it has been calculated that the cosmic-ray produced helium consists of ~30 percent He^3 isotope.[2] The He^3 is produced mainly in evaporations of the iron nuclei, both directly and through beta-decay from tritium.

The actual presence of He^3 in iron meteorites has now been established experimentally;[3] hence, it becomes possible to apply corrections to previously determined "ages"[4] (time since last solidification) by subtracting the cosmic-ray produced helium. One may also be able to place limits on the times of break up of the parent bodies and the dates of creation of the meteorites.[5]

It has also been pointed out[2] that this accumulating property of He^3, in effect, allows one to consider the meteorite as a kind of cosmic-ray meter which integrates the cosmic-ray flux it encounters over its path from the time it becomes exposed to cosmic rays to the time of its fall on earth. On the basis of certain assumptions,[2] it may thus be possible to gain information about the prehistoric cosmic-ray intensity.

The integrating-meter properties of meteorites are, of course, due to the fact that both He^3 and He^4 are stable. One may, however, also consider the possibility of using a radioactive species produced by cosmic rays as an indicator of the (essentially present-day) cosmic-ray intensity existing in the region from which the meteorite came.

Tritium nuclei are released in considerable quantities during evaporations of iron nuclei. Their rate of production (near the surface of a large meteorite) is calculated to be $\sim 2.5\times 10^5$ tritons per g of meteorite material per year under the same conditions as before.[2] With a constant rate of production secular equilibrium is soon established; after several half-lives the tritium content becomes $\sim 5\times 10^6$ atoms/g.

In a freshly fallen meteorite the tritium activity should be within range of detection. Immediately after fall the activity per g in the region of maximum tritium production (2–15 cm from the "pre-atmospheric"[6] surface) should be ~0.01 counts/sec; this activity decreases by only 5.8 percent every year. Should the cosmic-ray intensity experienced by the meteorite in the years just preceding its fall be different from the intensity near the earth, the *measured* activity would differ from the expected value in the same manner.

It may not be necessary to rely on an absolute measurement, since, in addition to calculating the activity expected, one could actually calibrate it to the cosmic-ray intensity near the earth. With successive flights in high altitude balloons one can easily achieve an exposure of 0.1 year for a 10^3 g mass of iron; it should then contain $\sim 2.5\times 10^7$ atoms of cosmic-ray produced tritium.

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[6] That is, before any part of the surface is removed by ablation in the earth's atmosphere.

Orbital Effect in Neutron-Electron Magnetic Scattering*

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THE spin-spin part ($\mathcal{H}_{SS}$) of the neutron-electron magnetic interaction has been considered in some detail in the literature,[1] while the spin-orbit part ($\mathcal{H}_{SL}$) associated with the interaction between the neutron magnetic moment and a moving electron has not. It is worth while to consider both of these in detail from the viewpoint of exploiting the scattering of thermal neutrons from magnetic materials as a tool for investigating the electronic structure of matter.

The magnetic Hamiltonian is

$$\mathcal{H}_{SS}+\mathcal{H}_{SL}=-\boldsymbol{\mu}_n\cdot\mathbf{H}^{(S)}-\boldsymbol{\mu}_n\cdot\mathbf{H}^{(L)}, \tag{1}$$

in which $\boldsymbol{\mu}_n=g_n(m/M_p)\beta\mathbf{s}_n$ is the neutron magnetic moment, and the magnetic field at the neutron generated by electrons of the scatterer is given by

$$\mathbf{H}^{(S)}=\Sigma_j\{-\boldsymbol{\nabla}_j\times[\boldsymbol{\mu}_j\times(\boldsymbol{\nabla}_j r_{nj}^{-1})]\}, \tag{2}$$

$$\mathbf{H}^{(L)}=\frac{e}{mc}\Sigma_j(\boldsymbol{\nabla}_j r_{nj}^{-1})\times\mathbf{p}_j, \tag{3}$$

where $\boldsymbol{\mu}_j=-2\beta\mathbf{s}_j$ is the magnetic moment, $\mathbf{r}_j$ the position, $\mathbf{p}_j$ the momentum, and $\mathbf{s}_j$ the spin angular momentum (in units of $\hbar$) of the jth electron, the summation being over all electrons; $\mathbf{r}_n$ is the position, $\mathbf{s}_n$ the spin, and $g_n=-3.83$ the g factor of the neutron; m/M_p is the electron-proton mass ratio; $\beta=e\hbar/2mc$ is the Bohr magneton; $r_{nj}=|\mathbf{r}_n-\mathbf{r}_j|$. These expressions for $\mathcal{H}_{SS}$ and

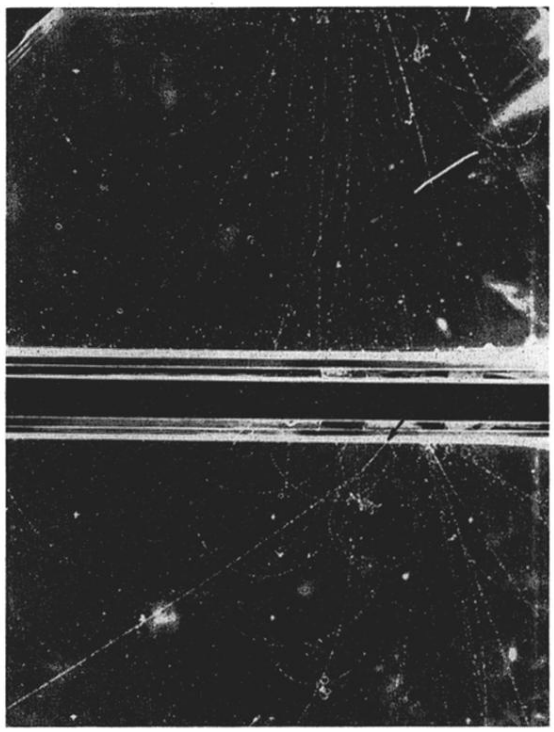

FIG. 1. Cloud-chamber photograph showing a charged V particle originating in an interaction in the lead plate and decaying into a heavy secondary particle. The V particle travels diagonally downward toward the left from the interaction and decays after having traversed only a short distance in the chamber. The heavy secondary particle proceeds almost in the same direction as the V particle. Both the primary and secondary particles are heavily ionizing.