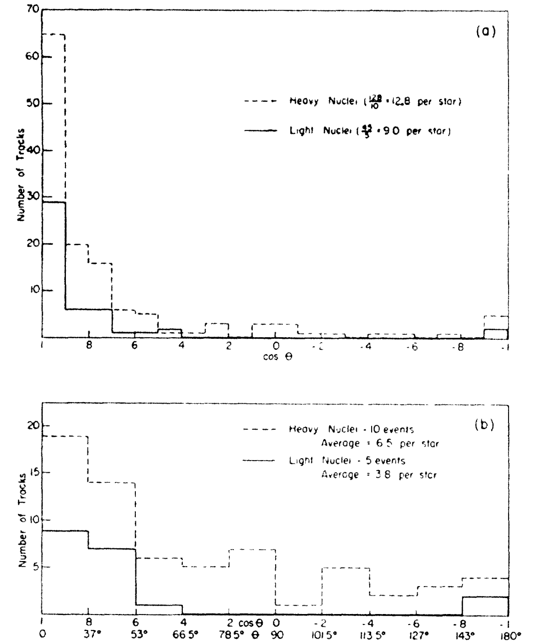

FIG. 1. Angular distribution, with respect to their shower axes, of (a) all minimum tracks (kinetic energy $>mc^2$) and (b) all near-minimum tracks (kinetic energy between 0.08 and 0.6 mc^2) from light and heavy nuclei.

The average angle with respect to the shower axis of the minimum tracks in each star *vs.* their multiplicity is plotted in Fig. 2. *For the same multiplicity of meson production, the angular spread is much smaller for light than for heavy nuclei.*

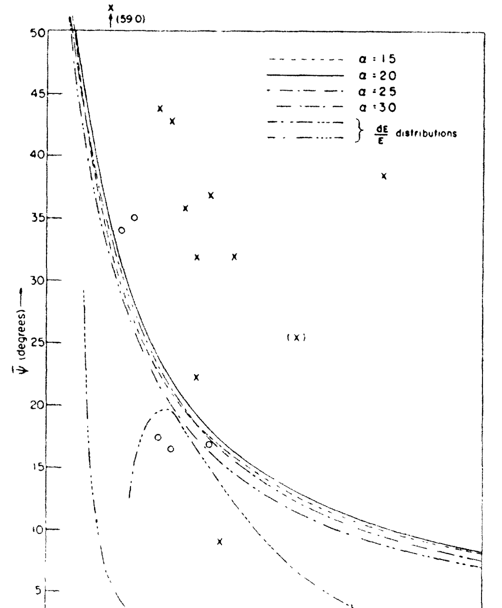

FIG. 2. Average angular spread of the minimum tracks *vs.* their multiplicity. The circles represent light nuclei; the crosses, heavy nuclei. The curves are predictions based on a completely inelastic single nucleon-nucleon collision, with a spherically symmetric angular distribution of charged mesons in the center of mass system. The upper group of four curves assume that all the mesons are produced with a single energy, α (total energy in meson rest energy units) in the center of mass system. The lower two curves assume a bremsstrahlung energy distribution, with high energy cut-offs at 0.155 and 1.0 times the energy available in the center of mass system.

The curves in Fig. 2 represent predictions of a simple theory in which all the charged mesons are produced in a single, completely inelastic nucleon-nucleon collision, with a spherically symmetrical angular distribution and various energy distributions in the center of mass system. The meson distributions from light nuclei are not in disagreement with these predictions; the heavy nuclei are in disagreement.

On the other hand, the fast proton component in the showers and the increased angular spread of showers from heavy, as compared to light, nuclei suggest that meson production in all nuclei is by a cascade process, with a small multiplicity in each nucleon-nucleon collision. Accordingly, nuclei must be considered opaque to high energy nucleons, and the observed[10] exponential absorption, with longer-than-geometric mean free path, of the star-producing radiation, must be explained in terms of the cascade multiplication process.

We are indebted to Mrs. T. Kallmes for much detailed observation.

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* Assisted by the Joint Program of the ONR and the AEC. We are especially grateful to J. Hornbostel and E. O. Salant, Brookhaven National Laboratory, for their cooperation in making available emulsions exposed at high altitudes.

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The Neutrons from the Disintegration of Beryllium by Deuterons*

W. D. Whitehead and C. E. Mandeville
Bartol Research Foundation of the Franklin Institute,
Swarthmore, Pennsylvania

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THE neutrons from the reaction $Be^9+D\rightarrow B^{10}+n+Q$ have been previously investigated by Bonner and Brubaker,[1] Powell and Fertel,[2] and Staub and Stephens.[3] In all three instances, a bombarding energy of less than 1 Mev was employed and neutron groups were observed corresponding to energy levels in the residual nucleus, B^{10}, at 0.65, 2.0, and 3.4 Mev.[4] More recently, Evans, Malich, and Risser[5] have noted the presence of an additional neutron group, endothermic in character, and corresponding to an excitation level in B^{10} at 5.13 Mev. Their estimated Q-value for this group is (−0.74) Mev. Indication of the endothermic group was obtained solely from an analysis of the counter data of the excitation curve for neutrons from $Be^9(D,n)B^{10}$, whereas in the earlier measurements,[1–3] recoil proton spectra of the neutrons were actually observed in cloud chambers and photographic plates.

In the measurements to be described, Ilford C_2 emulsions, located 10 cm from the target and making an angle of zero degrees with the incident deuterons, were irradiated by neutrons from the reaction $Be^9(D,n)B^{10}$. In order to activate the level in B^{10} corresponding to the endothermic Q-value, a mean bombarding energy of 1.62 Mev was employed to irradiate a beryllium target of thickness 100 kev. The energy spectrum observed in a microscope is shown in Fig. 1 where five groups of neutrons are seen to

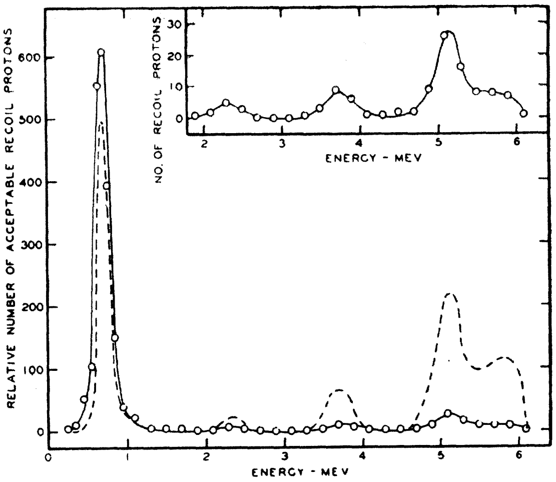

FIG. 1. Distribution in energy of the recoil protons of the neutrons from $Be^9(D,n)B^{10}$. The energy of the incident deuterons was 1.62 Mev.

be present having energies of 0.70, 2.32, 3.72, 5.17, and 5.86 Mev. In order to ascertain positively that the group of lowest energy was not distorted by the presence of neutrons from $C^{12}(D,n)N^{13}$, a carbon target also of thickness 100 kev was irradiated by deuterons at 1.62 Mev, and the recoil protons of the emitted neutrons were observed in C_2 plates. The observed peak of the monochromatic neutrons occurred at 1.14 Mev, showing clearly that the neutrons of carbon could have made no contribution to the group of lowest energy in Fig. 1. The Q-values given by the curve of Fig. 1 are -0.74, 0.73, 2.19, 3.70, and 4.39 Mev. In obtaining the Q-values, the observed neutron energies were increased to allow for the use of a finite angle of acceptance in the emulsions.

In a separate experiment, the same beryllium target was bombarded by deuterons of mean energy 1.15 Mev. The energy distribution of the recoil protons is shown in Fig. 2, where the endothermic group of the beryllium reaction has disappeared and has been replaced by the neutrons from $C^{12}(D,n)N^{13}$, since carbon had begun to form in appreciable quantity upon the surface of the target. Disappearance of the endothermic group at a bombarding energy of 1.15 Mev is attributed to the fact that the recoils of the neutrons of low energy did not make tracks of sufficient length to be distinguishable against the general background of the plates.

The energy levels in B^{10} calculated from Figs. 1 and 2 are 0.69 ± 0.10, 2.20 ± 0.10, 3.66 ± 0.10, and 5.13 ± 0.08 Mev. In Figs. 1 and 2, the energy distributions were corrected for variation with energy of the $n-p$ scattering cross section and acceptance probability as indicated by the broken line. It is to be noted that the relative intensities of the neutron groups fluctuate considerably with bombarding energy. From the areas under the curves and, assuming spherical symmetry in the c.g. system of coordinate axes, it is estimated that at $E_D=1.62$ Mev, the relative intensities are, in the order of ascending Q-value, 14.5, 1.9, 9.4, 35.6, and 38.6. At $E_D=1.15$ Mev, for the four beryllium groups, the relative intensities are 7, 15, 39 and 39.

Recently, spectrometric studies have been made of the gamma-rays related to the reaction $Be^9(D,n)B^{10}$. A gamma-ray of energy 5.20 Mev was observed, with an intensity amounting to about two percent of the total gamma-ray yield. The low intensity of the gamma-ray is in agreement with the fact that the total gamma-ray yield does not increase appreciably with the appearance of the endothermic group of neutrons.[5] It has been suggested,[6] therefore, that the following reactions occur:

$$Be^9+D\rightarrow {}^*B^{10}+n-0.74\text{ Mev},$$
$$ {}^*B^{10}\rightarrow Li^6+He^4+0.84\text{ Mev}.$$

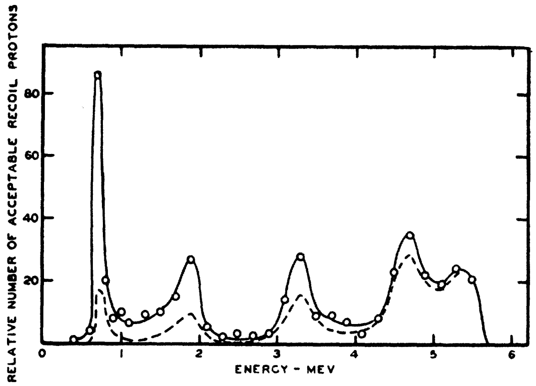

FIG. 2. Distribution in energy of the recoil protons of the neutrons from $Be^9(D,n)B^{10}$. The energy of the incident deuterons was 1.15 Mev. The group of lowest energy is from the reaction $C^{12}(D,n)N^{13}$.

The high probability of particle emission explains, of course, the low intensity of the nuclear gamma-ray at 5.20 Mev.

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* Assisted by the Joint Program on the ONR and the AEC.

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Evidence for a Charged Heavy Meson*

H. H. FORSTER
University of Southern California, Los Angeles, California

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IN the course of recent experiments with nuclear emulsion plates exposed for several hours at 30,000 feet an interesting cosmic-ray event was found which is discussed below. A photomicrograph of the event is shown in Fig. 1: A charged particle (track 1) enters the emulsion from the air and after progressing 50μ comes to rest in the emulsion. The end of its range is coincident with a nuclear disintegration in which 10 charged particles are ejected. One particle (track 8) is strongly scattered, stops in the emulsion and shows an increase in ionization typical for mesons. An enlargement of track 1 is shown in Fig. 2; with regard

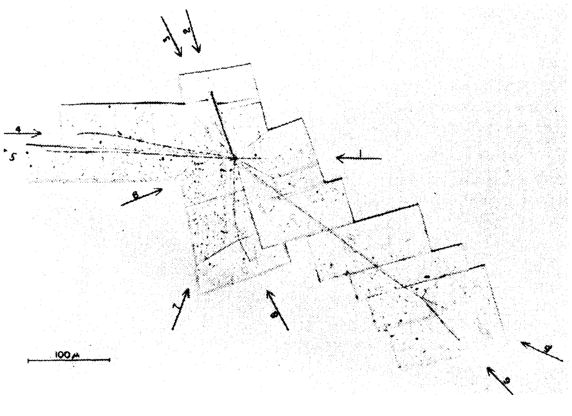

FIG. 1. Disintegration of a heavy nucleus originated by a charged particle coming to rest in the emulsion.