[1] C. F. Powell, Nature **161**, 473 (1948); I. Barbour, Phys. Rev. **74**, 507 (1948).
[2] I. Barbour, Rev. Sci. Inst. **20**, 530 (1949).
[3] Lattes, Fowler, and Cuer, Proc. Phys. Soc. **59**, 883 (1947).
[4] E. J. Williams, Phys. Rev. **58**, 292 (1940); Goldschmidt-Clermont, King, Muirhead, and Ritson, Proc. Phys. Soc. **61**, 183 (1948).
[5] For any range or path length, a given increment in deflection angle is essentially represented by the same number of deflection units in all parts of the scale. Mass values are averaged, weighted as the inverse squares of probable errors, on this scale.

A Large Nuclear Disintegration Produced by a Very High Energy Alpha-Particle of the Cosmic Radiation*

J. J. Lord, Marcel Schein, and M. Vidale
Department of Physics, University of Chicago, Chicago, Illinois
May 31, 1949

INFORMATION regarding the manner in which extremely high energy nuclei interact with other nuclei is so limited that the following event of this nature is described as has been observed on an Eastman NTB-3 photographic plate, 150 microns in thickness, exposed in the stratosphere through the use of free balloons. The nuclear collision, as indicated by the tracks of the onizing particles involved, is shown in Fig. 1.

The method of grain counting has been employed in order to obtain information as to the possible nature of each track. Since the grain density is a function of the energy loss per micron, this quantitative relationship was obtained by measuring the grain densities of several long proton and meson tracks ending in the emulsion, and tracks due to single charged particles at minimum ionization. The relationship between grain density and energy loss will not be given, since it was within statistical error the same as that published by Powell and his collaborators[1] for the Kodak NT-4 emulsion.

Track A, Fig. 1, extends from the nuclear disintegration throughout the emulsion for 38,000 microns to a point in the glass backing of the plate. The measured grain densities at points 0.0, 1.5, and 3.6 cm from the disintegration are respectively 0.99, 0.98, and 0.98 grains per micron, as given by counting at each point about 500 grains.

This track, A, cannot be due to a meson, proton, or deuteron, since with this grain density, their corresponding ranges would all be less than 38,000 microns. In addition, for the above mentioned particles, including the triton, the grain density should show a considerable change along the track. The remarkable constancy of the grain density along the 38,000 microns is, however, in perfect agreement with that due to an alpha-particle close to its maximum ionization.

An alpha-particle with this grain density, which is very close to the minimum for double charged particles, would have to have an energy in excess of 3 Bev. In the plane of the plate, which was located vertically, the track A makes an angle of about 15° with the vertical. These facts strongly indicate that the alpha-particle was most likely a part of the primary cosmic radiation.

Track A' is of interest, since the measured grain density along its 3550 micron range within the emulsion is constant, and is within statistical error, the same as that of track A. This grain density corresponds either to that of a 70 Mev proton (and other singly charged particles of correspondingly low energies), or an alpha-particle of at least 3 Bev. A consideration of the sum of the energies of the particles causing the tracks other than A and A' and an assumption of an equal energy for neutrons emitted leads to a total energy release in the star of roughly 1 Bev. Thus, since A carries a momentum corresponding to at least an alpha-particle of 3 Bev energy, and since the other tracks, excluding A and A', do not show any preferential direction, momentum can be conserved only if track A' is also assumed to be due to a very high energy alpha-particle. This is in perfect agreement with the measured grain density of A'.

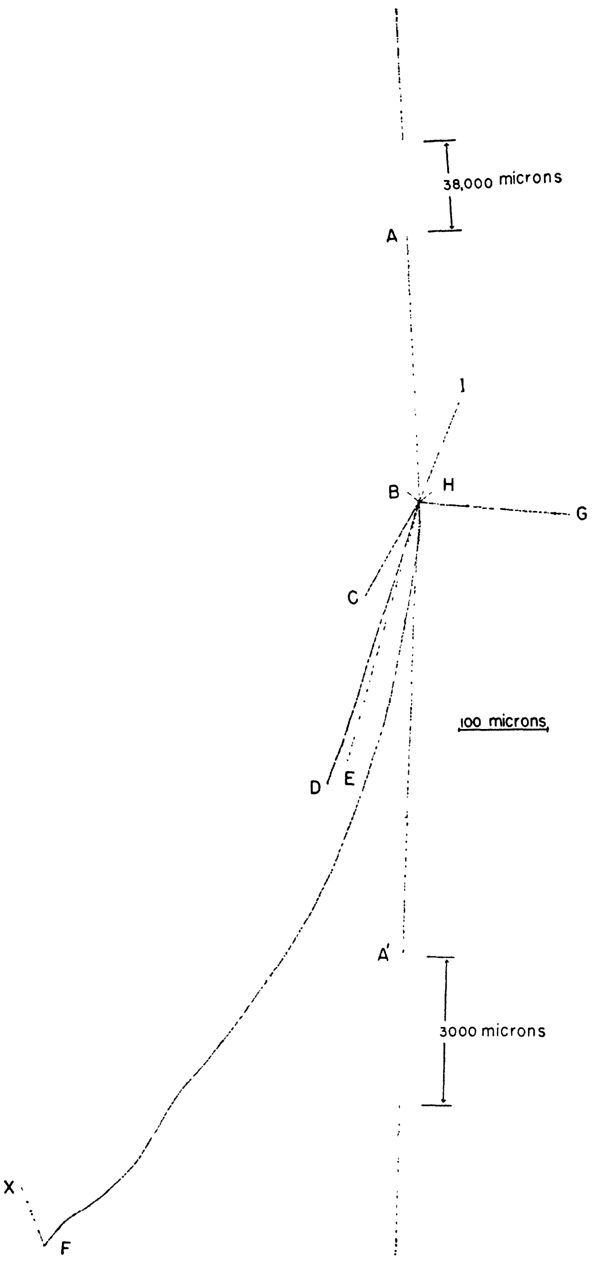

Fig. 1. Reproduction of a photograph showing a π-energy nuclear collision.

Tracks F and D end in the emulsion and were identified, respectively, as due to a π-meson and a proton. At the end of track F, a single track, X, of low grain density originates and passes into the glass backing after traversing 76 microns of emulsion. From its measured grain density track X could either be due to a μ-meson of energy, 4 Mev, or a proton of 31 Mev. The former view, which is more probable, would mean that tracks F was due to a positive π-meson undergoing the familiar decay to a μ-meson. The less likely alternative is that F could be due to a negative meson which, after stopping, is captured and produces a disintegration with the emission of a single ionizing particle with ionization which corresponds to that of a 31 Mev proton. However, it would be somewhat unusual if, as in this case, no other fragments of heavier nuclei occurred in the star.

This event is then interpreted as the collision of a primary alpha-particle of several Bev energy with a nucleus in the emulsion, which leads to the emission of several charged nucleons of energies estimated to be from 4 to 200 Mev and the production of a low energy π-meson. Since the alpha-particle lost an energy or more than 1 Bev in this encounter and then continued on with an angular deviation of 2.5°, its energy was greater than the cut-off energy for alpha-particles at 50° magnetic latitude.

* Assisted by the joint program of the ONR and the AEC.

[1] Brown, Camerini, Fowler, Murihead, Powell, and Ritson, Nature **163**, 47 (1949).

Angular Distribution of Neutrons from (*d,n*) Reactions*

C. E. Falk,** E. Creutz, and F. Seitz
Physics Department, Carnegie Institute of Technology, Pittsburgh, Pennsylvania
May 25, 1949

This letter gives further results of preliminary experiments on the angular distributions of neutrons from (*d,n*) reactions.[1] The theory explaining the phenomena of (*d,n*) reactions at high deuteron energies (approximately 200 Mev) is well known[2–4] and has been satisfactorily verified by experiments.[5] However, from the work of Roberts and Abelson[6] there is evidence that (*d,n*) reactions at comparatively low energies (about 13 Mev) cannot be explained by the present day theories.

Deuterons of approximately 16 Mev, produced by the University of Pittsburgh cyclotron which was made available to us through the courtesy of Dr. A. Allen, were used to bombard thick targets of various elements. The relative resulting neutron fluxes were then measured at different angles by means of threshold detectors. Different elements were used as targets in order to study distributions as functions of the atomic weight of the target and the Q value of the reactions as shown in Table I.

Table I. Targets used.

Target	A	Q	
$LiBO_2$	Li-6, 7 B-10, 11	+15 Mev +13.8 Mev −1.6 Mev	for Li for B for O
Be	9	+4.3 Mev	
Cu	63.64	~+8 Mev	
Au	197	~+8 Mev	

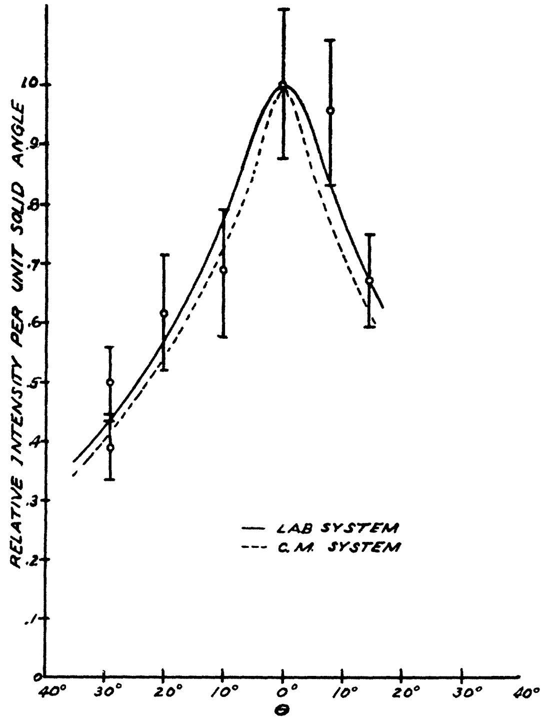

Fig. 1. Angular distribution of neutrons from $Au^{197}(d,n)Hg^{198}$ reaction. θ is angle between direction of maximum neutron intensity and other measured intensities.

Table II gives a list of the elements used for detection and the respective thresholds of the reaction.

Figures 1 and 2 show the resulting angular distributions for two typical cases, and Table III shows a summary of the experiments. It is immediately apparent that the distribution in all cases is sharply peaked in the forward direction. As there was a considerable amount of scattering of neutrons from the coils, poles, and the yoke of the cyclotron, small corrections had to be made for this effect. This was accomplished by a graphical integration of the effect over the complete area of the magnet pole pieces. Columns 4 and 5 in Table III show the corrected experimental half-widths (full width at half-maximum) of the angular distributions. The estimated experimental error in the listed half-width is ±10°. The magnitude of this experiment, however, makes it impossible as yet to determine the variation of the half-width of the distributions with A and Q.

Table II. Elements used for detection and threshold values.

Detector	Reaction	Half-life of product nucleus	Threshold energy	Reference
C^{12}	$C^{12}(n,2n)C^{11}$	20.5 min.	20.4 Mev	R. Sherr, Phys. Rev. **68**, 240 (1945).
Cu^{63}	$Cu^{63}(n,2n)Cu^{62}$	10.5 min.	12–13 Mev	R. Sagane, Phys. Rev. **53**, 492 (1938); E. O. Salant and N. F. Ramsay, Phys. Rev. **57**, 1075A (1940).
Ag^{107}	$Ag^{107}(n,2n)Ag^{106}$	24.5 min.	5–7 Mev	R. Sagane, Phys. Rev. **53**, 492 (1938); D. C. Graham and G. T. Seaborg, Phys. Rev. **53**, 795 (1938).
Al^{27}	$Al^{27}(n,p)Mg^{27}$	10.2 min.	~4.5	D. C. Graham and G. T. Seaborg, Phys. Rev. **53**, 795 (1938); Feld, Scalettar, and Szilard, Phys. Rev. **71**, 464 (1947).

Nevertheless, the results are of interest. In particular, the data for the gold is hard to reconcile with Serber's stripping theory.[3] Furthermore, the distinct directionality of the distribution is difficult to explain by a simple isotropic evaporation theory of a liquid drop compound nucleus.

Table III. Summary of experimental results.

Target	Detector	Reaction	Half-width of neutron distribution (lab. system)	(c.m. system)
$LiBO_2$	C	$Li^{6,7}(d,n)Be^{7,8}$	26°	23°
$LiBO_2$	Cu	$B^{10,11}(d,n)C^{11,12}$	30°	22°
$LiBO_2$	Ag		34°	27°
Be	Ag	$Be^9(d,n)B^{10}$	26°	18°
B_4C	C	$B^{10,11}(d,n)C^{11,12}$	34°	26°
Co	Cu	$Co^{59}(d,n)Ni^{60}$	26°	25°
Cu	Cu	$Cu^{63,65}(d,n)Zn^{64,66}$	26°	24°
Cu	Ag	$Cu^{63,65}(d,n)Zn^{64,66}$	48°	42°
Au	Ag	$Au^{197}(d,n)Hg^{198}$	49°	44°