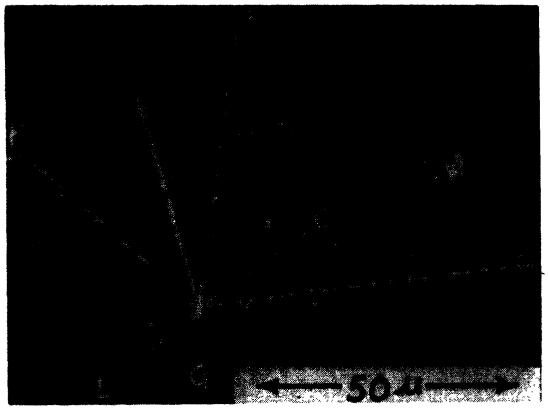

FIG. 1. Photomicrograph of the nuclear evaporation. ×44 dry objective with aperture reduced by dark field stop, 12.5× compensating eyepiece. The short recoil track, *G*, may not be visible in the reproduction.

observed in an Eastman NTA emulsion coated 30 microns thick, which resided in the laboratory at an elevation of 89 meters for 165 days prior to development.

On the basis of the mean grain spacing of the recorded track lengths, one trajectory can be attributed to an alpha-particle, and five to protons of varying energy. The short dense track *C* appears to terminate in the emulsion and may represent the recoil of the compound nucleus or the terminal track portion of the entrant particle. Its short length and unfavorable position near the center of the star does not permit evaluation of its grain density. If an equal number of neutrons accompanied the ejection of the protons, the event is consistent with the disintegration of an N^{14} atom in the gelatin layer. When observed under conditions of high resolving power the tracks are directed spatially in varied directions, two terminating in air and four entering the glass backing.

The energy of the protons was estimated from their grain counts with the aid of calibration data on grain density at the beginning of full length proton tracks recorded in an emulsion of identical stopping power. A study of the tracks of recoil protons produced in the emulsion by neutrons from a Be-Po source shows that the grain spacing near the track termination is essentially independent of proton energy, whereas at the beginning of the track it increases progressively with the total track length. This regularity permits an extrapolation of the proton energy, as the beginning of the tracks is sharply defined by the center of the star. Similar data is not available for high energy alpha-particles, but since the mean grain spacing of track *A* is only a trifle less than that observed in ThC′ alpha-tracks (0.56±0.02 microns) its total energy probably does not exceed 10 Mev.

The energy of the five protons totals 32 Mev and if an equal magnitude be assigned to the associated neutrons, then the disintegration is accompanied with the release of about 74-Mev energy. The breakdown of N^{14} into $He^4 + 5H^1 + 5n^1$ is endothermic and requires an additional energy expenditure of 76 Mev. The cosmic-ray particle causing the disintegration must therefore undergo a mass conversion equivalent to 150 Mev. The event is consistent with the entry and annihilation of a particle of about 300 electronic masses. The entrant particle might be a heavy meson, which according to Marshak and Bethe[5] has a mass of 250 electron masses.

---

[1] E. Gross, S. Kusaka, and G. Snow, Bull. Am. Phys. Soc. 22, 6 (1947).

[2] A. Zhadanov, Comptes Rendus U.R.S.S. 46, 359–61 (1945). Describes two events with 35- and 50-component tracks.

[3] G. R. Evans and T. C. Griffiths, Nature 159, 879 (1947). Observes star composed of eleven particles.

[4] R. R. Roy, Nature 160, 498 (1947). Describes nuclear burst with 22 tracks.

[5] R. E. Marshak and H. A. Bethe, Phys. Rev. 72, 506 (1947).

Excitation Function of the Reaction $C^{12}(p, pn)C^{11}$ at High Energies

W. HECKROTTE AND PETER WOLFF
Radiation Laboratory, Department of Physics, University of California
Berkeley, California

December 22, 1947

THE excitation curve for the reaction $C^{12}(p, pn)C^{11}$ at high energies has been measured recently by Chupp and McMillan.[1] Using the model of the nucleus described by Serber,[2] the excitation curve of the above reaction has been calculated for energies up to 100 Mev. The excitation of the nucleus is determined on the basis that the incident proton makes individual collisions with the nucleons, the transferred energy exciting the nucleus. The mean free path of a high energy nucleon in the C^{12} nucleus was taken to be $4.75 \cdot 10^{-13}$ cm at 100 Mev; and the radius of the C^{12} nucleus $3.7 \cdot 10^{-13}$ cm. These numbers are chosen to give a total cross section equal to the experimental value, $\sigma_t = 0.55$ barn.[3] The distribution curve for the energy transferred to the nucleus in one or more collisions was calculated by Mr. Baumhoff of this laboratory. $n-p$ collisions are taken to be three times more probable than $n-n$ or $p-p$ collisions. The calculations were made for both a pure $n-p$ exchange force and a half-exchange, half ordinary force.

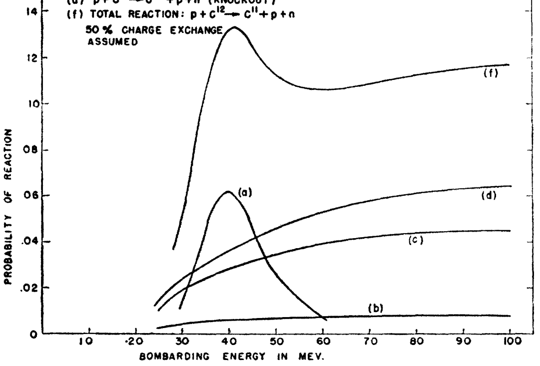

FIG. 1

The decay of the excited nucleus is treated by the usual evaporation model.

On the above basis, the reaction can go in four ways:

(a) $p+C^{12}\rightarrow N^{*13}$; $N^{*13}\rightarrow C^{11}+p+n$,
(b) $p+C^{12}\rightarrow C^{*12}+p$; $C^{*12}\rightarrow C^{11}+n$,
(c) $p+C^{12}\rightarrow N^{*12}+n$; $N^{*12}\rightarrow C^{11}+p$,
(d) $p+C^{12}\rightarrow C^{11}+p+n$ (knock out).

The part played by each of these separate reactions to give the total reaction is shown in Fig. 1 for 50 percent exchange. Reaction (a) contributes chiefly in the 40-Mev region. This is the result (1) of the high probability in this region of the incident particle giving up all of its energy in a few collisions and thus of being captured; and (2) of the energy dependence of the $N^{13}\rightarrow C^{11}+p+n$ reaction. Above the 40-Mev region there is an increased probability of boiling off three or more particles, and below the 40-Mev region, only one particle. Reaction (b) takes place when the incident proton passes through the nucleus and makes few collisions before emerging with most of its original energy. Because of the much greater probability of excited C^{12} breaking down into three α-particles, this reaction contributes very little to the total reaction. It does contribute somewhat more for 50 percent exchange since a one collision non-exchange process can then contribute. Reaction (c) is made possible by a net exchange taking place when the incident proton passes through the nucleus, so that it emerges as a neutron. Excited N^{12} is formed as the intermediate product. For small excitation energies (~10 Mev)N^{12} will definitely boil off one proton, but this probability rapidly drops off for higher excitation energies because of competing processes coming into play. As a result of this only a single $p-n$ exchange collision is effective in giving reaction (c), a two (or more) collision process leaving too much excitation energy. This results in making the reaction practically directly proportional to the amount of exchange, which, accordingly, exerts a direct influence on the yield of the total reaction at high energies. Reaction (d) is the knock-out reaction. It is assumed that a knock-out reaction can occur only if the nucleon struck by the incident particle travels from the point of collision to the outside of the nucleus without colliding with other nucleons. Otherwise the struck nucleon excites the nucleus by its collisions with the other nucleons and so stays in. The knock-out reaction (d) is probable only if the incident proton makes just the one collision near the edge of the nucleus.

The total reaction for both 50 percent and 100 percent exchange is plotted on a range scale in Fig. 2, assuming 140-Mev protons incident on a carbon block. The attenuation of the incident beam is taken into account. The experimental curve (1) for the reaction is given by the dotted line. The ordinate has been adjusted to bring it into approximate agreement with curve I.

The calculated cross section for the reaction at 62 Mev is: 0.046 barn for 50 percent exchange and 0.062 barn for 100 percent exchange. The experimental value[4] is 0.073 ±0.010 barn for 62-Mev incident protons.

The authors wish to express their great appreciation to Professor Robert Serber for his continued assistance throughout the course of these calculations.

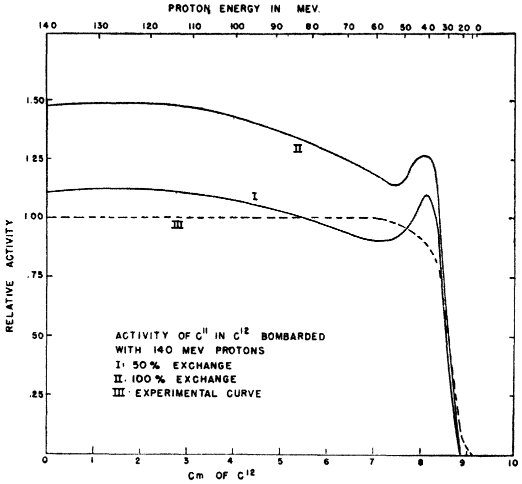

Fig. 2.

This paper is based on work performed under Contract No. W-7405-eng-48 with the Atomic Energy Commission in connection with the Radiation Laboratory, University of California, Berkeley, California.

---

[1] W. W. Chupp and E. M. McMillan, Phys. Rev. 72, 873 (1947).
[2] R. Serber, Phys. Rev. 72, 1114 (1947).
[3] L. J. Cook, E. M. McMillan, J. M. Peterson, and D. C. Sewell, Phys. Rev. 72, 1264 (1947).
[4] E. M. McMillan and R. D. Miller, Phys. Rev. 73, 80 (1948).

Excitation Function of the Reaction $C^{12}(n, 2n)C^{11}$ at High Energies

W. Heckrotte and Peter Wolff
Radiation Laboratory, Department of Physics, University of California, Berkeley, California
December 22, 1947

The excitation curve for the reaction $C^{12}(n, 2n)C^{11}$ has been calculated for energies up to 100 Mev. The calculations were done as described in the preceding letter for the similar reaction of C^{12} under proton bombardment.

The reaction can go in three ways:

(a) $n+C^{12}\rightarrow C^{*13}$; $C^{*13}\rightarrow C^{11}+2n$,
(b) $n+C^{12}\rightarrow C^{*12}+n$; $C^{*12}\rightarrow C^{11}+n$,
(c) $n+C^{12}\rightarrow C^{11}+2n$ (knock out).

The results of the calculations for 50 percent exchange are shown in Fig. 1. The calculated cross section for the reaction at 90 Mev is: 0.010 barn for 100 percent exchange and 0.012 barn for 50 percent exchange. The experimental value is 0.022±0.004 barn.[1]

The ratio of the cross section of the reaction $C^{12}(p, pn)C^{11}$ to the cross section of the above reaction at 90 Mev is: 5.8 for 100 percent exchange and 3.8 for 50 percent exchange. The experimental ratio is 3.3 at 90 Mev.[1]

This difference in cross sections between the two reactions is established by two factors. First, there is the part played by exchange in the $C^{12}(p, pn)C^{11}$ reaction which