$B^{10}(n,t2\alpha)$ and $B^{10}(n,dn'2\alpha)$ Reactions for 6–20 Mev Neutrons*

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In a set of B^{10}-loaded C-2 emulsions exposed to eight neutron energies in the range 6–20 Mev, 1541 three-prong stars were found which were caused by either the $B^{10}(n,t2\alpha)$ or the $B^{10}(n,dn'2\alpha)$ reaction. The triton cross section at 14 Mev is 102±17 mb and decreases with increasing bombarding energy, while the deuteron cross section is 128±19 mb and increases slightly with energy. The triton reaction proceeds partially through the 4.61-Mev state in Li^7 and partially as a three-body breakup. In the deuteron reaction the following intermediate nuclei are formed: Be^9, 2.43-Mev state; Be^8, ground state and possibly the 2.9-Mev level; Li^7, 10.8- and 12.4-Mev levels; and Li^6, 2.19-Mev level. Four examples were found of the $N^{14}(n,t3\alpha)$ reaction. The feasibility of using the $B^{10}(n,t2\alpha)$ reaction as a neutron monitor is discussed.

I. INTRODUCTION

SINCE the nuclei of mass $A=5$ through 9 are stable to charged particle breakup by at most 2.46 Mev, nuclear reactions which lead to these nuclei may often ultimately result in the emission of three or more charged particles at bombarding energies considerably lower than required in other parts of the periodic table. Nuclear emulsions or cloud chambers are particularly adapated to the study of reactions of this type, as they can record the ranges and angles of all the charged particles involved and thus give a more complete description of the process.

The reaction $B^{10}(n,t2\alpha)$, $Q=0.33$ Mev, has been observed previously in boron-loaded nuclear emulsions.[1–3] In the most extensive investigation Perkin[3] found evidence that Be^{8*}, excited to the 2.65-, 4.0-, 7.25-, 9.8-, and 13.5-Mev levels, was formed as an intermediate nucleus. Ribe and Seagrave[4] detected a group of deuterons from the 2.43-Mev state of Be^9 in the reaction $B^{10}(n,d)Be^{9*}$. Since this level in Be^9 is known to break up into a neutron and two alpha particles, it might be expected that three-prong stars would be found where one prong is a deuteron instead of a triton.

In the present experiment a series of B^{10}-loaded plates were exposed to neutrons of energy 5.6, 7.7, 12.2, 14.1, 16.1, 18.2, 19.3, and 20.0 Mev and searched for three-prong events. An analysis based on energy and momentum conservation is used to distinguish between events arising from $B^{10}(n,t2\alpha)$ and $B^{10}(n,dn'2\alpha)$, $Q=-5.93$ Mev. The cross section for each reaction is obtained as a function of bombarding energy, and the data are further analyzed to see what intermediate nuclei, if any, are formed.

II. EXPERIMENTAL PROCEDURE

Ilford C-2 B^{10}-loaded emulsions were exposed to neutrons of 12.2, 14.1, 16.1, 18.3, 19.3, and 20.0 Mev simultaneously with a series of nonloaded plates in an experimental arrangement described previously.[5] In addition, a check was made on the 14.1-Mev point by an exposure at the Cockcroft-Walton accelerator.[5] Two further plates were exposed to neutrons of 5.6 and 7.7 Mev produced at the Los Alamos large electrostatic accelerator by the $D(d,n)He^3$ reaction. After processing, the plates were soaked in a 10% glycerine solution to reduce shrinkage.

III. PLATE ANALYSIS

The plates were scanned for all three-prong events. It was necessary to establish a criterion to discriminate between boron and carbon stars, as the latter (which arise from $C^{12}(n,n'3\alpha)$, $Q=-7.28$ Mev) are much more numerous due mainly to the greater carbon content of the emulsion (270 mg/cc *vs* 21 mg/cc). Triton stars are always larger than carbon stars for the same bombarding energy, E_0, because the Q is greater by 7.61 Mev and the triton track may be quite long. Deuteron stars may also have a long deuteron prong, but the Q is only 1.35 Mev greater than for carbon stars, and if the scattered neutron carries away an appreciable fraction of the energy, the resulting deuteron star may be only slightly larger than a carbon star. The procedure adopted was for the scanner to make a quick calculation of a borderline case as a carbon star by adding together the energy represented in each of the three prongs taken as an alpha particle. This sum should be less than or equal to E_0+Q for a carbon star, since the energy of the scattered neutron has been neglected. If the sum was greater than E_0+Q, it could not have been a carbon star and the event was completely measured as described earlier.[5] Use of this criterion meant that some low-energy deuteron events were probably not recorded. However, these could not have been separated unambiguously from the carbon events even with a complete analysis. For this reason the deuteron cross sections represent a lower limit.

IV. STAR CALCULATIONS

No attempt was made to discriminate between the triton or deuteron and the alpha particle on the basis

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[1] H. J. Taylor, Proc. Phys. Soc. (London) **47**, 873 (1935).

[2] C. M. G. Lattes and G. P. S. Occhialini, Nature **159**, 331 (1947).

[3] J. L. Perkin, Phys. Rev. **81**, 892 (1951).

[4] F. L. Ribe and J. D. Seagrave, Phys. Rev. **94**, 934 (1954).

[5] Frye, Rosen, and Stewart, Phys. Rev. **99**, 1375 (1955).

of grain density. Instead balance of momentum and energy was used to distinguish the type of event and to identify the deuteron or triton prong. This required, in all, seven calculations on each event; one as a carbon star, three as a triton star taking each prong cyclically as the triton, and similarly three times as a deuteron star. From the energy and direction of the three prongs the bombarding energy, E_c, was calculated for the carbon and deuteron cases. For the triton calculations the energy of the three prongs minus Q is E_c, since there is no scattered neutron. The entire problem of calculating the seven E_c's from the raw data was coded for the IBM 701 Computer which picked the minimum $\Delta E_c = |E_c - E_0|$ as the correct choice. For the three triton cases the machine also calculated the momentum conservation between the incoming neutron, and the triton and two alpha particles. If the ΔE_c criterion gave a triton as the correct choice, the machine then picked out the case which gave the best momentum balance and compared this selection with the one given by ΔE_c. In a few percent of the cases the choices did not agree. These were found to be actually deuteron events where the difference in Q for the $B^{10}(n,t2\alpha)$ and the $B^{10}(n,dn'2\alpha)$ reactions and the difference in the range-energy relation for the various particles would fortuitously combine to give better fits as triton events. Of course momentum would not balance for these "trition" stars. The machine was instructed to remove from consideration the triton choice given by energy balance if it did not agree with the one given by momentum balance, and pick the next best ΔE_c. It was found that this procedure gave the correct designation every time in several hundred hand calculations. After the IBM 701 Computer had made the correct selection from the seven possibilities, it calculated the center-of-mass energies and angles of the three (or four) emitted particles and the various excitation energies discussed below.

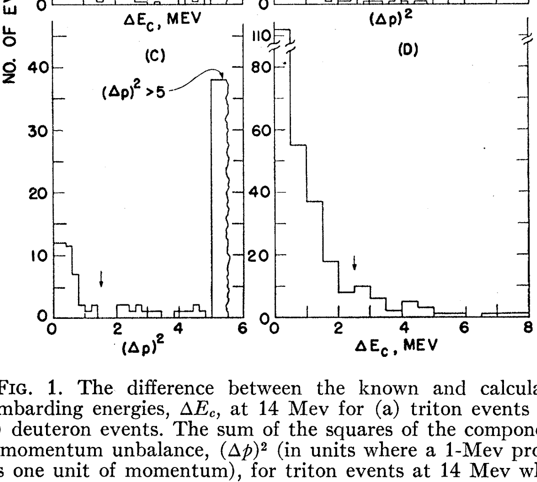

FIG. 1. The difference between the known and calculated bombarding energies, ΔE_c, at 14 Mev for (a) triton events and (d) deuteron events. The sum of the squares of the components of momentum unbalance, $(\Delta p)^2$ (in units where a 1-Mev proton has one unit of momentum), for triton events at 14 Mev where (b) all prongs end within the emulsion and (c) one prong leaves the emulsion surface. In each case the arrow indicates the largest acceptable value.

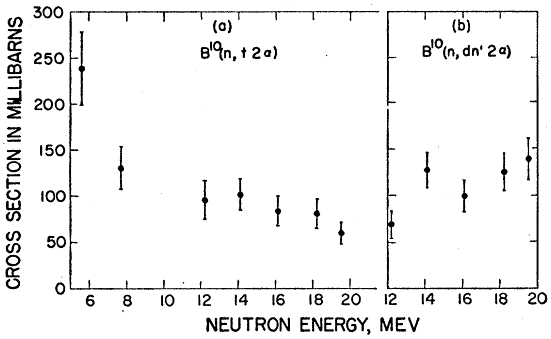

FIG. 2. Cross section *vs* bombarding energy for (a) $B^{10}(n,t2\alpha)$ and (b) $B^{10}(n,dn'2\alpha)$. The indicated errors are absolute.

Events were recorded even though one or more prongs went out the top or bottom of the emulsion surface before stopping. The computer was programmed to treat as triton cases the stars where only one prong went out, by using the energy equation to determine the energy of the out-of-surface track and then calculating the momentum balance. For the few cases where two or three prongs left the emulsion, conservation of momentum was used to determine the length of the out-of-surface tracks and the energy balance was calculated.

V. $B^{10}(n,t2\alpha)$ RESULTS

Figure 1 shows plots of ΔE_c and the sum of the squares of the three components of momentum unbalance $(\Delta p)^2$, in units where a 1-Mev proton has unit momentum, for triton events at 14 Mev which remained entirely within the emulsion. Also shown is the momentum unbalance for the events which had one out-of-surface prong. The tails on each of the histograms are caused mostly by steeply dipping tracks. To calculate the cross section, stars with $\Delta E_c < 1.5$ Mev and $(\Delta p)^2 < 1.5$ were used. The neutron flux was determined previously for $E_n = 12.2$ to 20.0 Mev.[5] The $D(d,n)He^3$ flux at 5.6 and 7.7 Mev was calculated from the cross section[6] and checked by measuring proton recoils in plates. A plate was exposed to a known thermal neutron flux and the B^{10} content so found agreed with Ilford's value (21 mg/cc) to within 10 percent. The average value of 21.9 mg/cc was used to determine the cross section. The boron distribution varied by less than 5%

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[6] J. E. Perry (private communication).

TABLE I. Cross section for $B^{10}(n,t2\alpha)$ as a function of neutron energy.

E_0 (bombarding energy in Mev)	No. of triton events	Cross section in mb
19.5	80	60±12
18.2	86	81±16
16.1	92	84±16
14.1	196	102±17
12.2	138	96±21
7.7	68	131±23
5.6	97	239±40

vertically and over different areas of the emulsion. The cross section as a function of bombarding energy is given in Fig. 2(a) and Table I; the points at 19.3 and 20.0 Mev have been combined to give one point at 19.5 Mev with better statistics. Contributions to the the absolute errors arise from uncertainties in the neutron flux, boron content of the plates, and emulsion thickness; a 10% allowance for possible observer inefficiency; and the statistical uncertainty. The comparatively large value of the cross section at $E_0=5.6$ Mev may be due to a resonance in B^{11} near this excitation energy (~16.6 Mev). A possible resonance in this region has been observed in the $Be^9(d,p)Be^{10}$ reaction.[7]

If it is postulated that the $B^{10}(n,t2\alpha)$ disintegration proceeds as a series of two-body reactions, either Li^{7*} or Be^{8*} may be formed as an intermediate nucleus depending on which decay chain is followed:

$$(1)\ B^{10}(n,\alpha_1)Li^{7*}(\alpha_2 t) \quad \text{or} \quad (2)\ B^{10}(n,t)Be^{8*}(\alpha_1\alpha_2).$$

To see which mode of disintegration is correct, the usual procedure is to assume first (1) and calculate the excitation of the Li^{7*} nucleus, and then (2) and calculate the excitation of Be^{8*}. Appearance of the known levels of Li^7 or Be^8 would be an indication of the formation of these nuclei. Experimentally the triton reaction is particularly nice in that, since there is no scattered neutron, each excitation energy may be determined in two ways. For instance, in (1) the excitation energy of Li^7, $E_{\text{ex}}(Li^7)$, may be found from E_0 and the energy and direction of α_1, and from the energies and directions of α_2 and t. Of course one does not know *a priori* which is α_1 and which is α_2, so two computations must be done on each star. E_0 and t, and α_1 and α_2 are used to obtain $E_{\text{ex}}(Be^8)$, and here there is no ambiguity.

The two determinations of $E_{\text{ex}}(Li^7)$ were averaged and the results shown as a function of E_0 in Fig. 3(a). Only events where the difference between the two determinations of $E_{\text{ex}}(Li^7)$ is less than 1 Mev are included; those where $0.5 \leqslant \Delta E_{\text{ex}}(Li^7) < 1.0$ Mev are indicated separately. At each neutron energy a peak is visible at 4.7 ± 0.5 Mev which may be identified with the known level at 4.61 Mev.[8] No other peak appears consistently at different bombarding energies. The corresponding calculation for $E_{\text{ex}}(Be^8)$, Fig. 3(b), shows no consistent levels. The absence of the broad 2.0-Mev level in Be^8 is particularly surprising as it seem to appear in reactions which can lead to Be^8 whenever energetically possible.[8] In particular the photodisintegration of B^{11}, which is also the compound nucleus in the subject reaction, has been interpreted as involving the 2.9-Mev state as well as other levels in Be^8 and the 4.6-Mev level in Li^7. It is felt that events leading to the ground state of Be^8 would have been seen if present, since they are found in the $C^{12}(n,n'3\alpha)$ and $B^{10}(n,dn'2\alpha)$ reactions where the observational difficulties are more formidable. [Although a peak is seen at $E_{\text{ex}}(Be^8)=3$ Mev for $E_0=5.6$ Mev, further analysis reveals that most of these events also have $E_{\text{ex}}(Li^7)$ near 4.6 Mev. Since the 3-Mev level in Be^8 is not evident at other bombarding energies, this cannot be taken as an indication of formation of this level at 5.6 Mev.]

Even though a value for $E_{\text{ex}}(Li^7)$ or $E_{\text{ex}}(Be^8)$ is found which agrees with a known level in one of the intermediate nuclei, this is no assurance that the intermediate state has actually been formed. However, an analysis of this type can establish the *maximum* number of times a certain level has been excited. The maximum fractional excitation of the 4.6-Mev level in Li^7 and the ground state and 3-Mev level in Be^8 is listed in Table II.

If the events which do go through the 4.6-Mev level in Li^7 are removed from Fig. 3(a), the remnant is fitted quite well by a three-particle phase space type of distribution[5] [Fig. 4(a)]. Also the angular distribution of the tritons from these stars is isotropic within the statistical accuracy [Fig. 4(b)]. Thus the mechanism of the triton reaction appears to be that in part of the events an alpha particle is emitted first which leaves Li^7 excited to the 4.6-Mev state, and the rest of the time the process is one of three-body breakup where the energy of the emitted particles follows a phase space distribution.

The angular distribution of all the tritons or alpha particles in the B^{11} center-of-mass system appears isotropic at each bombarding energy. The statistics were too meager to obtain an angular distribution of the first or second alpha particle in the events which

TABLE II. Maximum fractional excitation of the 4.61-Mev level in Li^7 and the ground state and 2.9-Mev level in Be^8, for $B^{10}(n,t2\alpha)$.

E_0 (bombarding energy in Mev)	Maximum fractional excitation of 4.61-Mev level in Li^7	Maximum fractional excitation of ground state of Be^8	Maximum fractional excitation of 2.9-Mev level in Be^8
19.5	0.35±0.10	0.02±0.02	0.04±0.03
18.2	0.46±0.12	0	0.08±0.04
16.1	0.44±0.09	0	0.07±0.03
14.1	0.45±0.07	0.01±0.01	0.08±0.02
12.2	0.55±0.09	0	0.14±0.04
7.7	0.74±0.15	0.02±0.02	0.36±0.09
5.6	0.93±0.14	0	0.64±0.11

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[7] Frederick L. Canavan, Phys. Rev. **87**, 136 (1952).

[8] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **27**, 77 (1955).

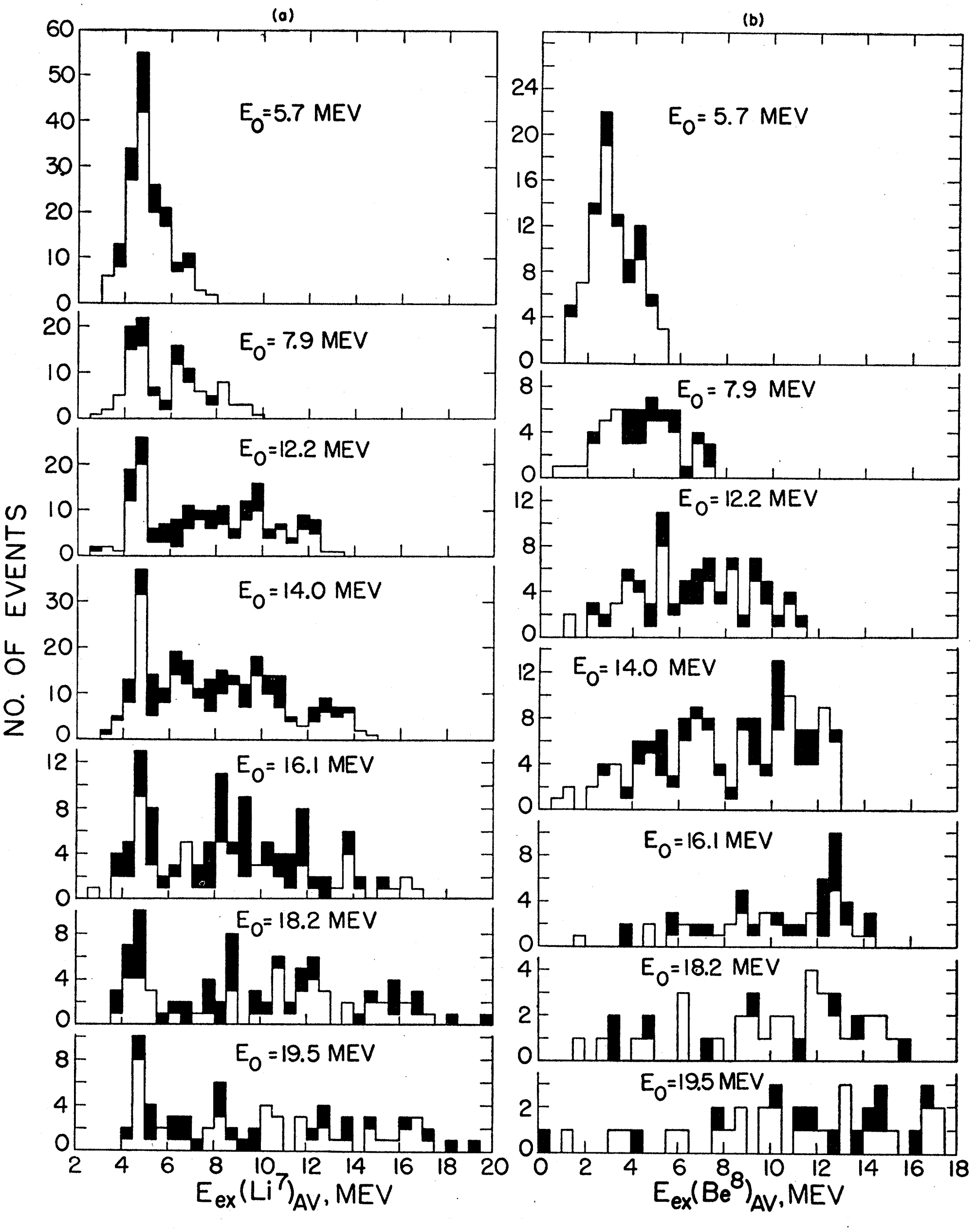

FIG. 3. Excitation energy of (a) Li^7 and (b) Be^8 for triton events, where the difference between the two determinations is <1.0 Mev. Shaded areas indicate $0.5<E_{ex}<1.0$ Mev.

followed the decay chain $B^{10}(n,\alpha_1)Li^{7*}(\alpha_2 t)$, $E_{ex}(Li^7)=4.6$ Mev.

VI. $B^{10}(n,dn'2\alpha)$ RESULTS

The cross section for this reaction is summarized in Fig. 2(b) and Table III. A plot of ΔE_c at 14 Mev is given in Fig. 1(d). Since E_c can no longer be calculated for deuteron events when one prong goes out the surface, two less-direct corrections were made. (a) All the out-of-surface events which did not give a $(\Delta p)^2<1.5$ when calculated as triton events, were recalculated to determine whether they were possible deuteron events, i.e., whether a prong of the same direction and longer than the length in emulsion of the out-of-surface track would give $E_c=E_0$. This obviously leads to an upper limit for the number of deuteron stars. (b) A correction was made to each deuteron event in which no prong left the emulsion surface to determine the fraction of the cases for which it would have been an out-of-surface event. Thus for each star a number $A=1+(d_+ + d_-)/\text{E.T.}$ was used in calculating the cross section, where d_+ and d_- are the largest (+) and (−) dips present in the star and E.T. is the emulsion thickness. This correction is exact as long as the boron distribution is uniform vertically in the emulsion and there are no events where one prong goes out the top and another out the bottom

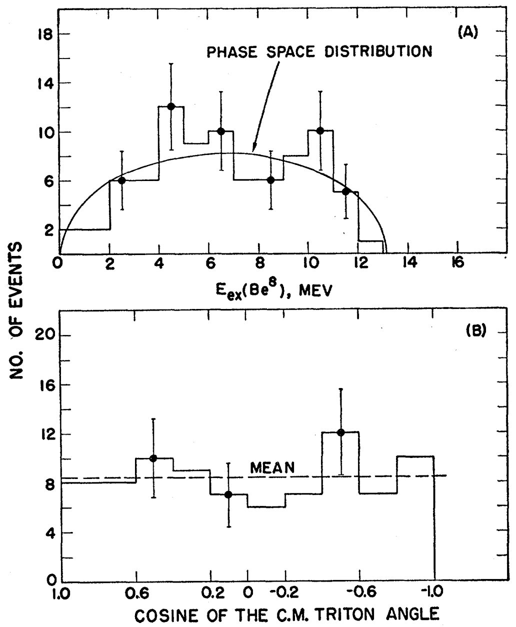

FIG. 4. (a) $E_{ex}(Be^8)_{Av}$ at 14 Mev for triton events where $E_{ex}(Li^7) < 4$ or > 5.5 Mev. The phase space curve is normalized to the total number of events. (b) Angular distribution of the triton in the B^{11} center-of-mass system for the same events. For each histogram a few typical statistical uncertainties are shown.

surface, as is the case at 16.1 Mev and below. At 18.2 and 19.5 Mev (a) yields a larger cross section then (b), as expected, and the value for σ was taken as the average of (a) and (b) with an additional uncertainty of half the difference between the two.

To make sure that no carbon stars were included in the deuteron cases, E_c was calculated separately for each deuteron event taken as a carbon star. Then for each E_0 a plot was made of ΔE_c(carbon) *vs* ΔE_c(deuteron). It was found that the points separated into two regions according as ΔE_c(carbon) is greater than or less than ΔE_c(deuteron)+2 Mev. Only the events which satisfied the former inequality sign were accepted. Of course some deuteron stars may have been eliminated by this procedure, so the deuteron cross sections quoted are in this sense a lower limit. The deuteron cross sections are also low in that some events in the category $B^{10}(n,d)Be^{9*}$, $E_{ex}(Be^9) = 2.4$ Mev were not observed, as is discussed below. On the other hand, some events from the reaction $B^{10}(n,p2n2\alpha)$, $Q = -8.16$ Mev, may have been included as deuteron events because effects of the lower Q and the taking of the proton range as a deuteron range would tend to cancel in the ΔE_c calculation.

TABLE III. Cross section for $B^{10}(n,dn'2\alpha)$ as a function of neutron energy.

E_0 (bombarding energy in Mev)	No. of deuteron events	Cross section in mb
19.5	191	140±23
18.2	135	126±20
16.1	110	100±17
14.1	248	128±19
12.2	100	69±15

A greater number of disintegration modes are available in the deuteron reaction than in the triton reaction, since four particles are emitted instead of three. If one assumes that each step is a two-body decay, there are six possibilities:

(1) $B^{10}(n,n')B^{10*}(d)Be^{8*}(\alpha_1\alpha_2)$,
(2) $B^{10}(n,n')B^{10*}(\alpha_1)Li^{6*}(d\alpha_2)$,
(3) $B^{10}(n,d)Be^{9*}(n')Be^{8*}(\alpha_1\alpha_2)$,
(4) $B^{10}(n,d)Be^{9*}(\alpha_1)He^{5*}(n'\alpha_2)$,
(5) $B^{10}(n,\alpha_1)Li^{7*}(n')Li^{6*}(d\alpha_2)$,
(6) $B^{10}(n,\alpha_1)Li^{7*}(d)He^{5*}(n'\alpha_2)$.

From the measurements of the three prongs, the excitation energies of all the intermediate nuclei except He^{5*} may be calculated. For instance, d taken with E_0 gives $E_{ex}(Be^9)$; d and α_2 give $E_{ex}(Li^6)$; d, α_1 and α_2 taken together yield $E_{ex}(B^{10})$, etc. In principle $E_{ex}(He^5)$ could be found from the measurements on α_2 and the deduced energy and momentum of the scattered neutron, n'. However, an error in measurement on any one of the three prongs is reflected in the determination of n', and consequently $E_{ex}(He^5)$ cannot be calculated to a suitable accuracy. Figure 5 shows the results for the excitation energies of B^{10}, Be^9, Be^8, Li^7, and Li^6, respectively. The following levels occur at each E_0: Be^9—2.43 Mev, Be^8—ground state and possibly 2.9 Mev, and Li^6—2.19 Mev, indicating that these intermediate nuclei are formed.

The most detail can be given about decay chain (3). Stars which involve the 2.43-Mev level in Be^9 can undergo transitions to the ground state of Be^8 only (disintegration into an α plus He^5 is energetically forbidden by 0.09 Mev). And this is verified experimentally, as every event where the deuteron leaves Be^9 in the 2.43-Mev state passes through the ground state of Be^8. At 14 Mev Ribe and Seagrave[4] found a cross section of 16±2 mb in the forward hemisphere for $B^{10}(n,d)Be^{9*}$, when $E_{ex}(Be^9) = 2.4$ Mev. We find a cross section of 18 mb for this mode of disintegration. However, only 6 mb of this is in the forward hemisphere. The explanation of this discrepancy is that we do not observe any events at small deuteron angles because the alpha particles have too small an energy in the lab system (~0.1 Mev), and, since they arise from the disintegration of the ground state of Be^8($E_{ex} = 0.1$ Mev), have a small angular separation. Thus the probability is very low of observing such an event when the deuteron comes off at a center-of-mass angle less than 50° (the Butler peak in the angular distribution is at 30°). Ribe and Seagrave[4] found an isotropic component of 1.5 mb/sterad in the forward hemisphere, so that the 12 mb we find in the backward hemisphere is consistent.

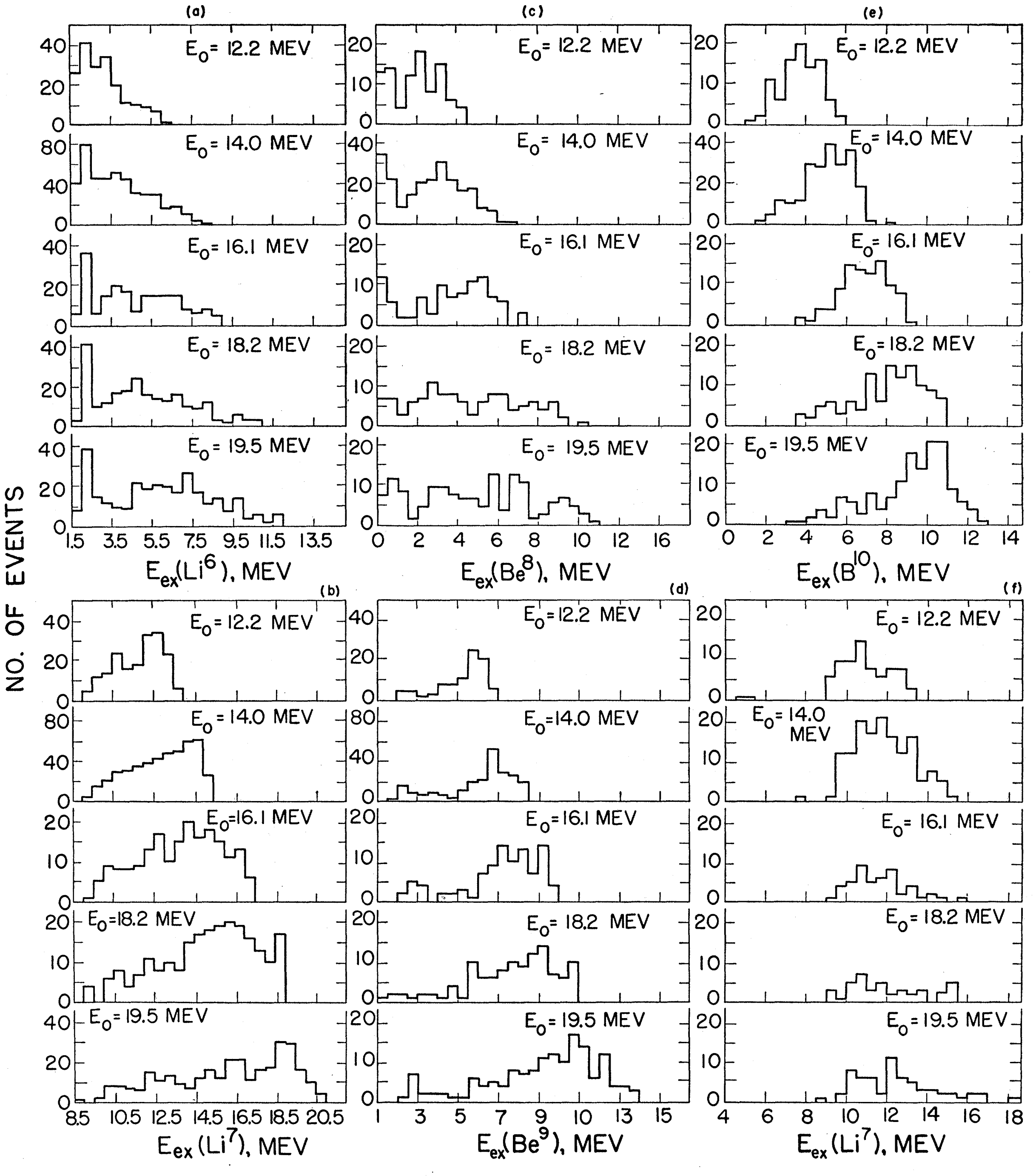

FIG. 5. Excitation energy of (a) Li^6, (b) Li^7, (c) Be^8, (d) Be^9, and (e) B^{10} for deuteron events, where $\Delta E_c < 2.5$ Mev. (f) Excitation energy of Li^7 for those deuteron events where $1.5 < E_{ex}(Li^6) < 3.0$ Mev.

Taking their value for the forward hemisphere and ours for the backward one, the total cross section at 14 Mev for $B^{10}(n,d)Be^{9*}$, $E_{ex}(Be^9) = 2.43$ Mev, is 28 ± 4 mb.

There are other events which involve the ground state of Be^8 but not the 2.43-Mev level of Be^9. However, a plot of $E_{ex}(B^{10})$ or $E_{ex}(Be^9)$ for these stars shows no consistent peaks so there is no evidence of (1) or for a level other than 2.43 Mev in (3). Also, a plot of $E_{ex}(B^{10})$ or $E_{ex}(Be^9)$ of the events that may involve the 3-Mev level in Be^8 does not yield a consistent peak.

Either (2) or (5) must also be a disintegration mode, since Li^{6*} is formed in the 2.2-Mev state at each E_0. When the spurious values corresponding to 1.5 Mev

TABLE IV. Maximum fractional excitation of the 2.19-Mev state in Li^6 for $B^{10}(n,dn'2_\alpha)$.

E_0 (bombarding energy in Mev)	Maximum fractional excitation of 2.19-Mev level in Li^6
19.5	0.44±0.06
18.2	0.44±0.08
16.1	0.50±0.09
14.1	0.63±0.07
12.2	0.78±0.12

$\leqslant E_{\text{ex}}(Li^6) \leqslant 3.0$ Mev are removed, there is still no evidence for other levels in Li^6. Moreover, these events show no consistent peaks for $E_{\text{ex}}(B^{10})$. In a histogram of $E_{\text{ex}}(Li^7)$, however, peaks are present at 10.7±0.5 and 12.2±0.5 Mev which may be identified with the levels at 10.8 and 12.4 Mev that are known to decay by neutron emission[9] [Fig. 5(f)].

Decay chains (3) and (5) are thus definitely established. The others, of course, are not eliminated because the level spacing may be less than the resolution in E_{ex} [especially in $E_{\text{ex}}(B^{10})$ which would be formed at very high excitation energies], and the statistical precision is poor. Confirmation of (4) and (6) was not possible, since $E_{\text{ex}}(He^5)$ could not be calculated. The assumption that each step in the decay chain is always a two-body one is probably not valid. Simultaneous three- or four-body disintegration may well take place in a manner similar to the three-body disintegration of the triton stars.

The maximum fractional excitation of the 2.19-Mev state in Li^6 is tabulated in Table IV. Similar computations were not made for $E_{\text{ex}}(Be^9) = 2.43$ Mev and $E_{\text{ex}}(Be^8) = 0$ Mev, since it is known that not all these events are observed, nor for $E_{\text{ex}}(Li^7) = 10.8$ or 12.4 Mev because these two levels were not sufficiently resolved.

The angular distributions of all the neutrons, deuterons, or alpha particles at each bombarding energy show no significant deviations from isotropy in the B^{11} center-of-mass system within the rather poor statistical accuracy.

VII. $N^{14}(n,t3\alpha)$

Although no consistent search was made for four-prong stars, two four-prong events were found at $E_0 = 18.2$ Mev and two at 19.3 Mev which are due to the reaction $N^{14}(n,t3\alpha)$, $Q = -11.29$ Mev. This reaction is an analog of $B^{10}(n,t2\alpha)$, as N^{14} contains one more alpha particle than B^{10} and an additional alpha particle is emitted as a reaction product. No examples were found of the known reaction[10] $O^{16}(n,n'4\alpha)$, $Q = -14.43$ Mev.

VIII. $B^{10}(n,t2\alpha)$ REACTION AS A NEUTRON MONITOR

The $B^{10}(n,t2\alpha)$ reaction in nuclear emulsions has been previously suggested as a neutron monitor which has several unique advantages.[2] Since there is no scattered neutron, the direction as well as the energy of the incoming neutron may be determined. Also the three-prong star is a distinctive type of event and can thus be readily distinguished from a variety of other reactions in the emulsion. In practice the deuteron reaction complicates the situation above 10 Mev. Below 10 Mev the triton reaction cannot compete with proton recoils as a neutron detector for a point source, because the atomic concentration of hydrogen (3×10^{22} atoms/cc) is much greater than the atomic concentration of boron (1.3×10^{21} atoms/cc for normal loading). However, it does offer a possible method for measuring the neutron flux from an extended source as a function of energy and direction in the energy range 4–10 Mev.

ACKNOWLEDGMENTS

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[9] J. Goldemberg and L. Katz, Phys. Rev. **95**, 471 (1954).

[10] D. I. Wanklyn, Phys. Rev. **90**, 381 (1953).