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AN INVESTIGATION OF SOME (t,d) REACTIONS IN LIGHT NUCLEI AT 5.5 MEV

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ABSTRACT. A broad range magnetic spectrograph has been used to analyse the deuterons emitted from targets of natural boron, carbon, silicon dioxide and aluminium bombarded with 5.5 MeV tritons. The angular distributions of the majority of the deuteron groups from the reactions observed in ^{10}B, ^{12}C, ^{13}C, ^{16}O, ^{27}Al and ^{28}Si have been measured and information has also been obtained on (t,d) reactions in ^{24}Mg, ^{28}Si, and ^{40}Ca because of the presence of these nuclei as impurities in the targets. In all cases the measured excitations of the final nuclei are in good agreement with the accepted values. The angular distributions have been compared with the stripping theory and also with published data on (d,p) transitions between the same initial and final nuclear states. Where possible the ratios of the yields of corresponding (t,d) and (d,p) reactions have been compared with the predictions of

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stripping theory; these results show marked deviations from those of previous comparisons between (d,t) and (d,p) reactions.

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1. INTRODUCTION.

In this work, (t,d) reactions in several light target nuclei have been investigated using a triton beam of 5.53 MeV incident energy. Deuteron groups leading to discrete levels in the final nuclei have been observed and angular distributions and absolute cross sections have been measured. Little previously published information is available at present on (t,d) reactions induced at similar, or higher, bombarding energies.

The primary aim of these experiments was to verify the predictions of the theory of single particle stripping from mass 3 particles (Newns 1952; Butler and Salpeter 1952; Butler and Hittmair 1957) as in the case of a previous investigation of some (^{3}He,d) reactions (Forsyth et al 1960). At the maximum bombarding energies available by acceleration in the Manchester University Van de Graaff generator, the (t,d) reaction is more suitable for this purpose than the (^{3}He,d) reaction since Coulomb effects will be less important. Also, as discussed by Forsyth et al, it is of particular interest to compare the behaviour of the mass-3 stripping reactions with the corresponding deuteron stripping reaction between the same initial and final states. For the (t,d) reactions comparison may be made with the (d,p) reactions which have, in general, been studied more widely and thoroughly than the (d,n) reactions which were used for comparison with the results of the (^{3}He,d) reaction.

In the present work deuterons were observed, using a broad range magnetic spectrograph, in a series of exposures with targets of natural boron, carbon, silicon dioxide and aluminium. Most of the experimental details have already been given in an account of the (t,p) reactions which were recorded simultaneously on the same photographic plates (Jaffe et al. 1960).

2. RESULTS.

2.1 Spectra.

In the course of this investigation deuteron groups leading to levels of ^{11}B, ^{13}C, ^{14}C, ^{17}O, ^{25}Mg, ^{28}Al, ^{29}Si, ^{40}K and ^{41}Ca were observed. The measured excitation energies of these nuclei, which are shown in the Table 1, were in excellent agreement with the values given by Ajzenberg-Selove and Lauritsen (1959) and Endt and Braams (1957). The results for the individual targets are discussed below.

(a) Natural boron target.

This target consisted of a 30μg cm^{-2} layer of natural boron evaporated on to a 14 μg cm^{-2} carbon foil. Spectra of the deuterons observed at 60^o to the incident beam for two different field settings are shown in Figure 1. Deuteron groups leading to the ground state and the first six excited states of ^{11}B at 1)2.126,

2) 4.449, 3) 5.027, 4) 6.769, 5) 6.806 and 6) 7.301 MeV were identified. These excitations were determined with an accuracy of ± 10 KeV. Deuterons from the $^{11}B(t,d)^{12}B$ reaction were absent because it has a relatively low Q-value (-2.894 MeV).

The reaction $^{13}C(t,d)^{14}C$ was observed due to the presence of ^{13}C in the natural carbon backing for the boron target.

As can be seen in the spectra shown in Fig. 1 deuteron groups from the reactions in ^{16}O, ^{24}Mg, ^{28}Si, ^{39}K and ^{40}Ca, which were present as contaminants, were also observed. The contamination amounted to about 12% of the total target thickness (Muto et al. 1960). The following reactions were observed in these nuclei: $^{16}O(t,d)^{17}O$ (ground state); $^{24}Mg(t,d)^{25}Mg$ (ground state, 0.569, 0.973 MeV); $^{28}Si(t,d)^{29}Si$ (ground state, 1.271, 2.025 MeV); $^{39}K(t,d)^{40}K$ (ground state); $^{40}Ca(t,d)^{41}Ca$ (ground state, 1.937, 2.456 MeV). The excitations were determined with an accuracy of ± 6 KeV. The deuteron groups to the third excited state of ^{29}Si at 2.426 MeV and the second excited state of ^{41}Ca at 2.014 MeV (Endt and Braams 1957) were not detected above the background.

(b) Carbon target.

The ground state deuteron group from the $^{12}C(t,d)^{13}C$ reaction was observed from the triton bombardment of a 35 $\mu g\ cm^{-2}$ thick natural carbon target and this group was also present on spectra obtained with each of the other targets, since carbon films were used as backing in each case.

The relative intensities of this group from the different targets were used to verify the consistency of the measurements of the thickness of the targets.

(c) Silicon dioxide target.

As can be seen from the spectrum shown in figure 2, the reactions leading to the ground state of ^{17}O and the excited state at 0.865 ± 0.005 MeV were observed and also those leading to the fourth, fifth and ninth excited states of ^{29}Si at measured excitations of 3.071, 3.630 and 4.936 MeV (± 0.010 MeV) respectively. The deuteron groups leading to the sixth, seventh and eighth excited states of ^{29}Si at 4.078, 4.840 and 4.897 MeV (Endt and Braams 1957) could not be studied from these spectra because the sixth excited state group was always obscured by elastically scattered deuterons, and the seventh and eighth excited state groups are avidently very weak (maximum differential cross section less than 0.01 mbn sterad^{-1}).

(d) Aluminium target.

Deuteron groups leading to the ground state of ^{28}Al and to excited states at 1) 0.030, 2) 0.973, 3) 1.020, 4) 1.370, 5) 1.630, 6) 2.138, 7) 2.203, 8) 2.279, 9) 2.489, 10) 2.582, 11) 2.664 MeV, (± 5 KeV) are shown in figure 3.

The excitation energies corresponding to groups leading to higher excited states of ^{28}Al could not be measured accurately since at most of the angles these groups were either obscured by elastically scattered deuteron groups or were not recorded on the plates.

2.2 Angular distributions and differential cross sections.

The angular distributions and differential cross sections for the deuteron groups observed from the above targets are shown in figure 4 to 7. The maximum absolute cross sections are given in Table I and the accuracy was estimated to be ± 15%.

Little information on the reaction $^{16}O(t,d_1)^{17}O$ could be obtained since the deuteron group was observed only at a limited number of angles. The angular distribution appeared to peak close to the 0° direction but observations could not be made below 20° (c.of m.) where the measured differential cross section was 1 mbn sterad $^{-1}$.

The d_2 group from the $^{27}Al(t,d)^{28}Al$ was too weak (0.06 mbn sterad $^{-1}$) to yield a reliable angular distribution. The d_5 and d_{10} groups from this reaction had angular distributions which were isotropic to within 30% and average differential cross sections of 0.40 and 0.15 mbn sterad $^{-1}$, respectively.

Apparently reliable angular distributions of the deuteron groups arising from the (t,d) reactions in the ^{24}Mg, ^{28}Si, and ^{40}Ca impurities in the boron target were obtained, and these are shown in figure 6. Further (t,d) transitions arising from these and other impurities were observed but the angular distributions could not be constructed because the deuteron groups overlapped with each other or were obscured by larger groups arising from $^{10}B(t,d)^{11}B$ reactions.

3. DISCUSSION OF RESULTS.

3.1 Angular distributions.

The results described above have been compared with the predictions of the Butler theory of stripping as applied to (^{3}He,d) and (t,d) reactions (Butler and Salpeter 1952, Butler and Hittmair 1957, Forsyth et al 1960). Most of the transitions observed in the present investigation have been previously studied via (d,p) reactions and this data has been reviewed by Macfarlane and French, (1959), who have reanalysed the results in a uniform manner using the Butler theory of (d,p) stripping. The numerical table of Butler-Born approximation stripping cross sections computed by Lubitz (1957) and used by Macfarlane and French to analyse the (d,p) results have also been used here to fit the angular distributions and to compare the magnitude of the absolute differential cross sections with the predictions of the Butler theory.

The ℓ-values which gave the best fit with the (t,d) angular distributions were invariably found to be the same as had been required to fit those of the corresponding (d,p) reactions. Also, similar values of the interaction radius were used, as can be seen in the table I. This reflects the close similarity between the corresponding (d,p) and (t,d) angular distributions which even extends to the deviations from the theoretical curves observed for many of the studied transitions, as is mentioned below.

$^{10}B(t,d)^{11}B$ - The angular distributions of the d_0, d_2, d_3 and d_4 groups (Figure 4) exhibit similar deviations from the theoretical curves as those of the corresponding proton groups from the

$^{10}B(d,p)^{11}B$ reaction studied at 7.7 MeV by Evans and Parkinson (1954)*. The relatively high yield of the d_0, d_2 and d_3 groups at large angles, which cannot be explained by simple stripping theory, has also been observed in the angular distributions of the corresponding proton groups in the (d,p) investigation mentioned above. The relative yields to different excited states of the (t,d) and (d,p) reactions are closely similar. The high cross section for the (t,d) reaction leading to the fourth excited state confirms the single-particle character of this state indicated by the (d,p) results of Evans and Parkinson. The d_1 group is weak and has an angular distribution which cannot be explained by the simple stripping theory, although there is some evidence of an $\ell = 1$ component. A similar result was obtained in a previous observation of the mirror reaction $^{10}B(^3He,d_1)^{11}C$ (Forsyth et al. 1960) and it was suggested that other direct interaction mechanisms might be responsible for the anomalous behaviour. The angular distributions of the p_5 and p_6 groups from the (d,p) reaction in ^{10}B, leading to excited states of ^{11}B at 6.81 and 7.30 MeV, respectively, have not been reported (Ajzenberg-Selove and Lauritsen, 1959). The d_5 and d_6 angular distributions can be fitted assuming

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* Although Evans and Parkinson (1954) could not resolve the fourth and fifth excited state proton groups from the (d,p) reaction, the transition leading to the fifth excited state has been observed to be relatively weak by Van Patter et al (1951). As can be seen in Table I, the intensity of the d_5 group is considerably smaller than that of the d_4 group. Hence it is reasonable to compare the angular distribution of the unresolved p_4 and p_5 groups with that of the d_4 group.

$\ell = 1$ which is consistent with the tentative assignments of spins and parities of $3/2^-$ and $5/2^-$ for the fifth and sixth excited states of ^{11}B (Ajzenberg-Selove and Lauritsen, 1959). The low cross section for the transition leading to the fifth excited state is consistent with this state having a mixed configuration as would be required by the shell-model calculations of Kurath (1956).

$^{12}C(t,d)^{13}C$, $^{16}O(t,d)^{17}O$, $^{13}C(t,d)^{14}C$ - The angular distributions of the deuteron groups from these reactions (Figure 5) were fitted with the stripping theory using the ℓ-values obtained from the corresponding (d,p) results (Macfarlane and French, 1959).

$^{24}Mg(t,d)^{25}Mg$ - Although the theoretical fits of the d_o and d_1 angular distributions (Figure 6) must be regarded as tentative since the deuteron groups arose from the small ^{24}Mg contamination of the boron target, the ℓ-values and radii employed agree well with the parameters used in previous investigations of the corresponding (d,p) reactions (Holt and Marsham, 1953a; Hinds et al 1958).

$^{27}Al(t,d)^{28}Al$ - The theoretical fits to the angular distributions shown in Figure 7 have been made using the ℓ-values obtained from investigation of the corresponding (d,p) reaction (Enge et al 1956). The radii which yield the best fits are in good agreement with those used by Enge et al. except for those cases ($\ell = 0$) where the peaks of the angular distributions were not observed thus making the fits uncertain. Although some of the angular distributions show complex structures, the deviations from the theoretical curves are generally closely similar to those observed in the corresponding (d,p) angular distributions. For example, the large cross sections of the d_3 and d_8 groups at small angles were observed for the p_3 and p_8 groups by the above authors who employed small $\ell = 0$ components to improve the fits of the angular distributions of these groups. Both the (t,d) and (d,p) transitions to the fifth and tenth excited states of ^{28}Al are approximately isotropic. The relative yields of the (t,d) and (d,p) reactions leading to different excited states of ^{28}Al are also in excellent agreement.

$^{28}Si(t,d)^{29}Si$ - The angular distributions shown in Figure 6 have been fitted with Butler theory using the ℓ-values indicated by the investigation of the corresponding (d,p) reactions by Holt and Marsham (1953b). However, the proton angular distributions leading to the fourth and fifth excited states of ^{29}Si required an $\ell = 0$ component which does not appear to be present in the (t,d) angular distributions.

$^{40}Ca(t,d)^{41}Ca$ - Once again the theoretical fits (see Figure 6) are tentative since the ^{40}Ca was present as a contaminant in the boron target, but the ℓ-values used agree with those employed to fit the corresponding (d,p) angular distributions (Bockelman and Buechner, 1957) though the radii are slightly smaller.

3.2 The absolute cross sections.

For those angular distributions in which the experimental points showed a maximum within the angular range studied, a comparison of the measured peak differential cross sections with predictions of the theory yielded values of $(2J_f+1)|A_o|^2 N_i{}^2 \theta^2$. The quantity $(2J_f+1)\theta^2$, where J_f is the spin of the final nucleus and θ^2 is the nucleon reduced width, has in many cases been calculated by Macfarlane and French (1959) from the results of previous investigations of the (d,p) reaction. Hence the proportionality factor $|A_o|^2 N_i^2$, which is related to the structure of the triton and is defined by Butler and Hittmair (1957), could be extracted for these transitions and the values obtained are listed in Table II. The errors associated with the (t,d) and (d,p) cross sections are such that an experimental accuracy of about ± 50% should be assigned to these values. A comparison of the yields of the corresponding (t,d) and (d,p) transitions characterised by an $\ell = 0$ component could not be made reliably since the peaks of the (t,d) angular distributions were outside the range of observation. The values of $|A_o|^2 N_i^2$ obtained in this way should be treated with reserve and are shown in parenthesis in Table II.

Recently, Macfarlane and French (1959) have reviewed the available data on (d,t) reactions in target nuclei between ^{6}Li and ^{23}Na. For each reaction analysed they evaluated a factor, Λ, which is directly proportional to the quantity $|A_o|^2 N_i^2$ as defined by Butler and Hittmair and adopted in this paper. The averaged value of Λ which they obtained is 195± 35, which is equivalent to a value of 13.6×10^{12} cm^{-1} for $|A_o|^2 N_i^2$. As can be seen in the table, the values of this quantity for the (t,d) reactions in ^{10}B, ^{12}C and ^{13}C nuclei compare reasonably well with the above value. However those obtained for heavier target nuclei are significantly low. It might be possible to explain the values for ^{27}Al(t,d) ^{28}Al and ^{28}Si(t,d)^{29}Si reactions in terms of Coulomb interactions as has been suggested in the case of the (^{3}He,d) investigations (Forsyth <u>et al</u>. 1960). Also Macfarlane and French observed a gradual reduction in Λ from lighter to heavier nuclei. However, the abnormally low value of $|A_o|^2 N_i^2$ for the $^{16}O(t,d)^{17}O$ reaction does not follow this trend and cannot be readily explained.

4. CONCLUSIONS.

The angular distributions of the observed (t,d) reactions at 5.5 MeV can be fitted with the Butler theory of deuteron stripping modified to the case of mass-3 particles. The degree of agreement is then about as good as that obtained with the corresponding (d,p) reactions. The results indicate, however, that the use of an average value of the quantity $|A_o|^2 N_i^2$ to extract information on nucleon reduced widths from mass-3 reactions is not justified.

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TABLE I

1.	2.	3.	4.	5.	6.
$^{10}B(t,d_o)^{11}B$	0	1	5.5	5.0[a]	5.2(18°)
$^{10}B(t,d_1)^{11}B$	2.126	1	6.5	6.0[a]	0.6(24°)
$^{10}B(t,d_2)^{11}B$	4.449	1	5.5	5.5[a]	4.0(25°)
$^{10}B(t,d_3)^{11}B$	5.027	1	5.5	5.5[a]	1.6(25°)
$^{10}B(t,d_4)^{11}B$	6.769	1	5.5	5.0[a]	20.0(14°)
$^{10}B(t,d_5)^{11}B$	6.806	1	5.5	-	0.6(14°)
$^{10}B(t,d_6)^{11}B$	7.301	1	5.5	-	1.9(14°)
$^{12}C(t,d_o)^{13}C$	0	1	6.0	4.5[b]	34.0(13°)
$^{13}C(t,d_o)^{14}C$	0	1	5.9	5.4[c]	22.3(18°)
$^{16}O(t,d_o)^{17}O$	0	2	5.3	5.1[d]	9.8(19°)
$^{24}Mg(t,d_o)^{25}Mg$	0	2	5.7	5.3[e]	-
$^{24}Mg(t,d_1)^{25}Mg$	0.569	0	5.7	5.3[e]	-
$^{27}Al(t,d_o)^{28}Al$	0	0	7.0	6.6[f]	13.6(12°)
$^{27}Al(t,d_1)^{28}Al$	0.030	0	7.5	6.6[f]	8.7(12°)
$^{27}Al(t,d_3)^{28}Al$	1.020	2	5.5	5.4[f]	1.7(33°)
$^{27}Al(t,d_4)^{28}Al$	1.370	2	5.5	-	2.7(33°)
$^{27}Al(t,d_6)^{28}Al$	2.138	0	6.5	6.6[f]	2.0(12°)
$^{27}Al(t,d_7)^{28}Al$	2.203	2	5.5	5.4[f]	0.7(23°)
$^{27}Al(t,d_8)^{28}Al$	2.279	2	5.5	5.4[f]	1.1(16°)
$^{27}Al(t,d_9)^{28}Al$	2.489	0	6.5	6.6[f]	0.3(16°)
$^{27}Al(t,d_{11})^{28}Al$	2.664	2	5.5	5.4[f]	1.1(17°)
$^{28}Si(t,d_o)^{29}Si$	0	0	5.7	5.4[g]	-
$^{28}Si(t,d_1)^{29}Si$	1.271	2	5.7	5.4[g]	-
$^{28}Si(t,d_4)^{29}Si$	3.071	2	4.5	5.4[g]	0.3(44°)
$^{28}Si(t,d_5)^{29}Si$	3.630	3	6.7	5.4[g]	1.8(33°)
$^{28}Si(t,d_9)^{29}Si$	4.936	1	6.7	5.4[g]	1.4(23°)
$^{40}Ca(t,d_o)^{41}Ca$	0	3	4.6	6.0[h]	-
$^{40}Ca(t,d_3)^{41}Ca$	2.456	1	5.1	6.0[h]	-

(1) Reaction, (2) measured excitation (MeV), (3) ℓ-value, (4) radius (10^{-13}cm), (5) radius used by Macfarlane and French (1959) in (d,p) analyses (10^{-13}cm), (6) differential cross section at the centre-of-mass angle shown (mbn sterad^{-1}).

Footnote:

(a) Evans and Parkinson (1954), (b) Green and Middleton (1956), (c) McGruer _et al_. (1955), (d) Burge _et al_. (1951), (e) Holt and Marsham (1953a), (f) Enge _et al_. (1956), (g) Holt and Marsham (1953b), (h) Bockelman and Buechner (1957).

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TABLE 2

1.	2.	3.	4.	5.
$^{10}B(t,d_0)^{11}B$	1	0.80	0.044[a]	18.2
$^{10}B(t,d_2)^{11}B$	1	0.46	-	-
$^{10}B(t,d_3)^{11}B$	1	0.20	-	-
$^{10}B(t,d_4)^{11}B$	1	2.28	-	-
$^{10}B(t,d_5)^{11}B$	1	0.06	-	-
$^{10}B(t,d_6)^{11}B$	1	0.26	-	-
$^{12}C(t,d_0)^{13}C$	1	0.48	0.066[b]	7.3
$^{13}C(t,d_0)^{14}C$	1	0.71	0.063	11.2
$^{16}O(t,d_0)^{17}O$	2	0.48	0.35	1.3
$^{27}Al(t,d_0)^{28}Al$	0	0.71	0.15	(4.8)
$^{27}Al(t,d_1)^{28}Al$	0	0.33	0.08	(4.4)
$^{27}Al(t,d_3)^{28}Al$	2	0.47	0.13	3.5
$^{27}Al(t,d_4)^{28}Al$	2	0.06	-	-
$^{27}Al(t,d_6)^{28}Al$	0	0.62	0.05	(12.3)
$^{27}Al(t,d_7)^{28}Al$	2	0.17	0.04	4.3
$^{27}Al(t,d_8)^{28}Al$	2	0.30	0.11	2.7
$^{27}Al(t,d_9)^{28}Al$	0	0.09	0.01	(9.0)
$^{27}Al(t,d_{11})^{28}Al$	2	0.29	0.11	2.7
$^{28}Si(t,d_4)^{29}Si$	2	0.03	0.01	3.0
$^{28}Si(t,d_5)^{29}Si$	3	0.13	0.10	1.3
$^{28}Si(t,d_9)^{29}Si$	1	0.11	0.05	2.2

(1) Reaction, (2) ℓ-value, (3) $(2J_f+1)|A_o|^2 N_i^2 \theta^2$ (10^{12} cm^{-1}), (4) $(2J_f+1)\theta^2$, calculated by Macfarlane and French (1959) from the results of the (d,p) investigations listed in the footnote of Table 1. (5) $|A_o|^2 N_i^2$ (10^{12} cm^{-1}).

(a) The value obtained by Jaffe and Husain (1960) at 6 MeV, (b) the value reported by Mayo and Hamburger (1960).

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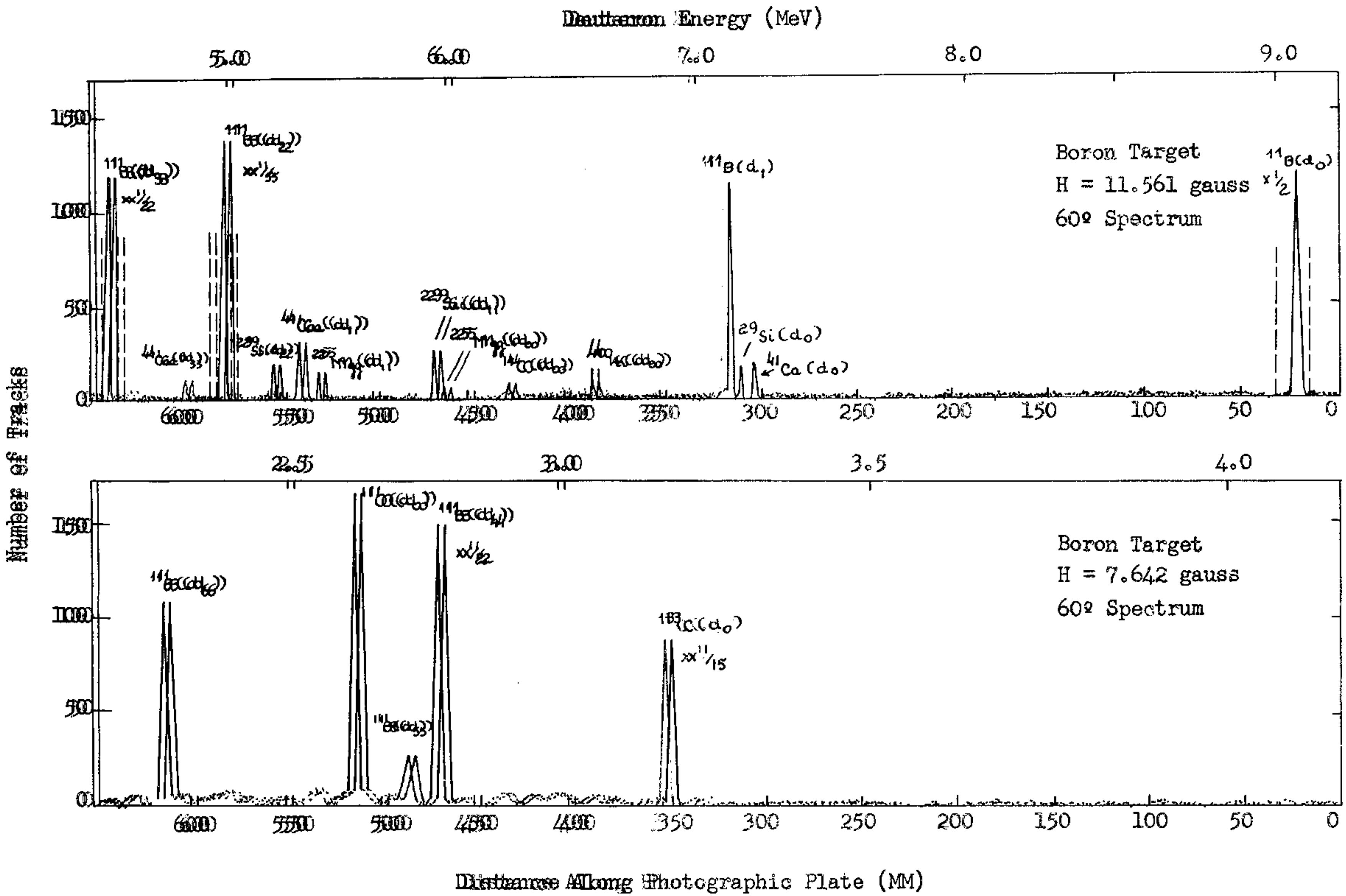

Deuteron Energy (MeV)
Boron Target
H = 11.561 gauss
60º Spectrum
Boron Target
H = 7.642 gauss
60º Spectrum
Number of Tracks
Distance Along Photographic Plate (MM)

Fig. 1

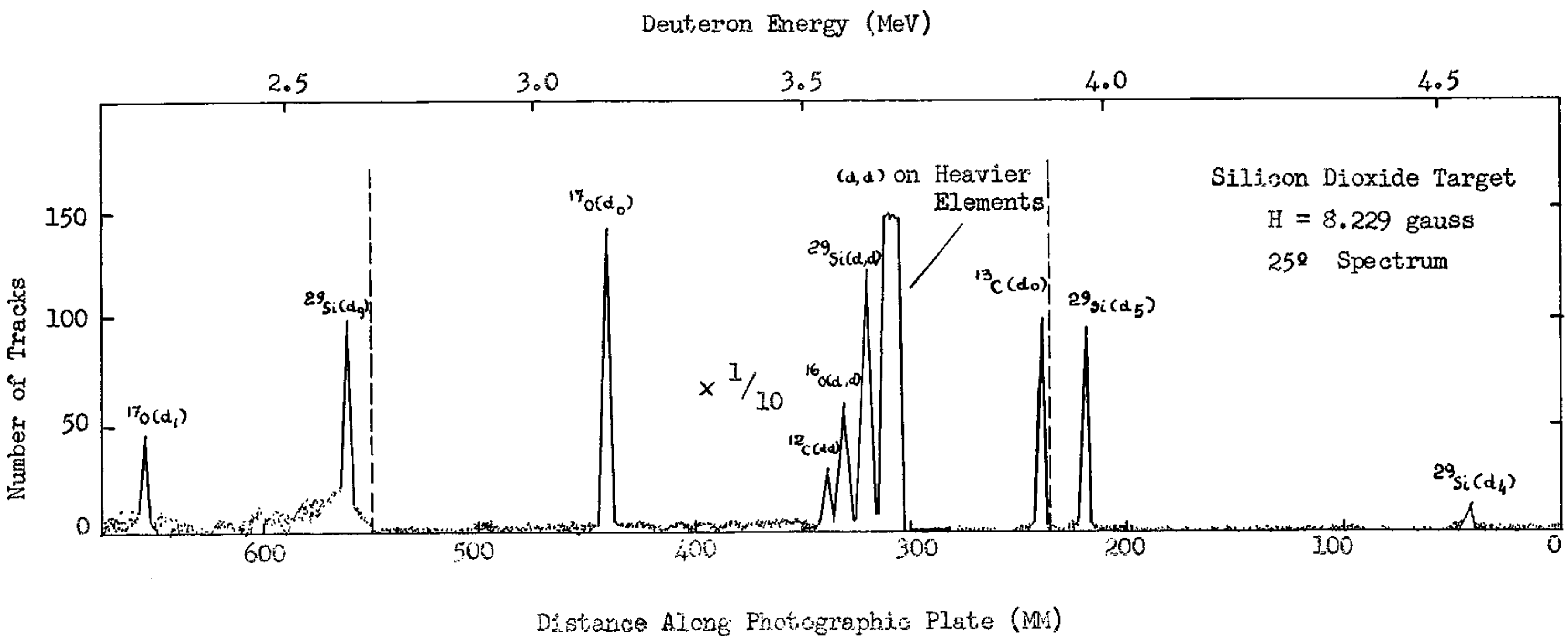
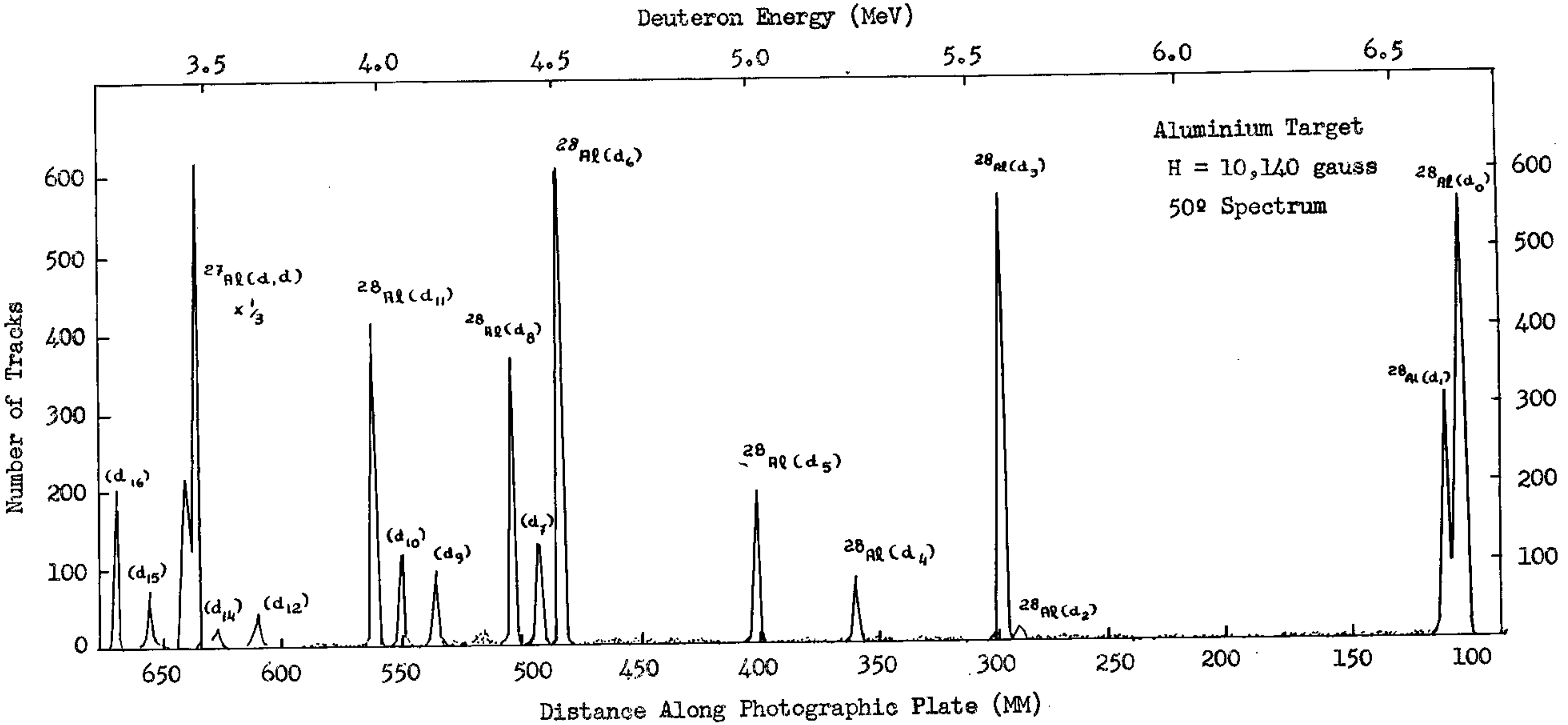
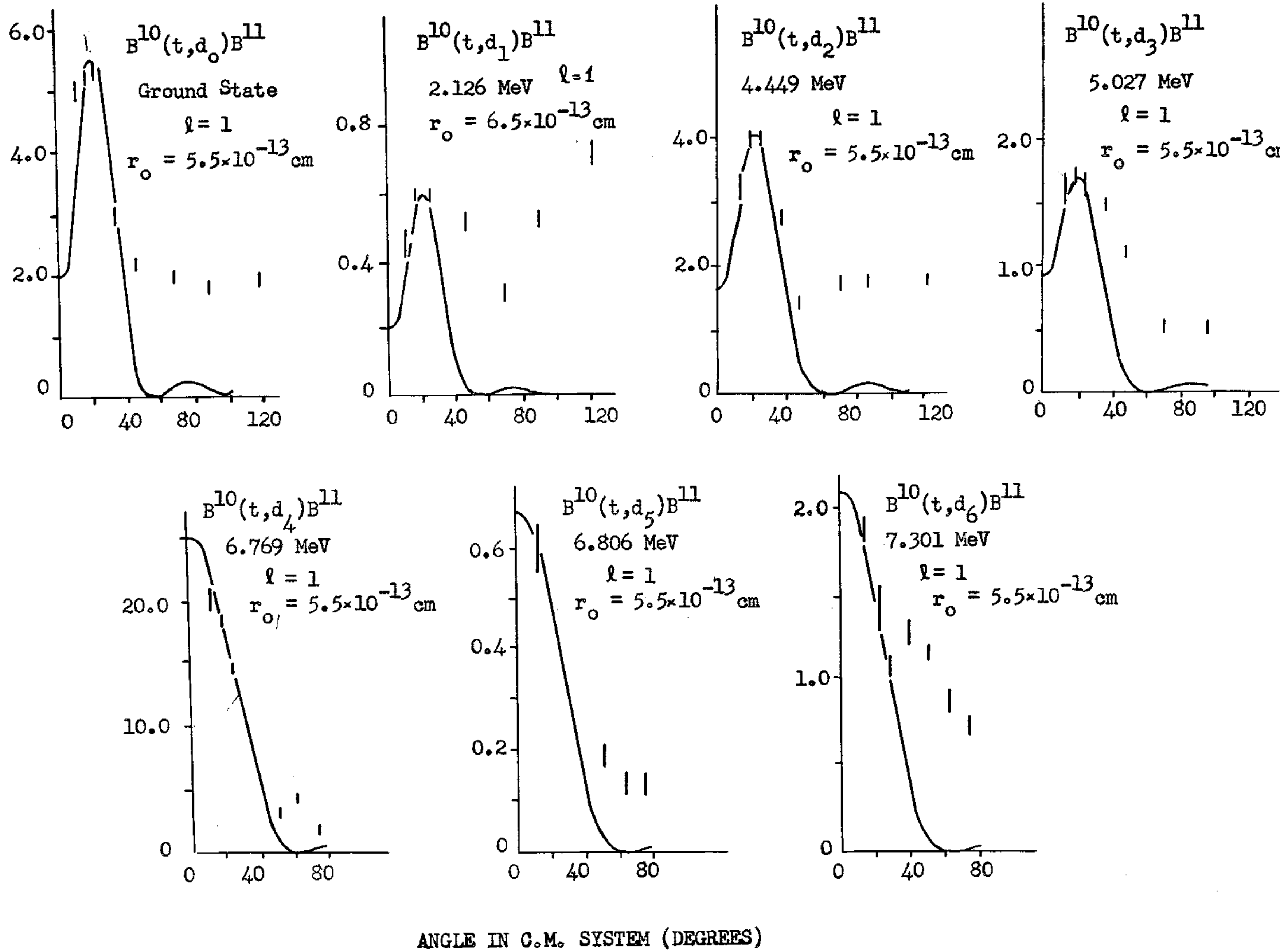

Deuteron Energy (MeV)
2.5
3.0
3.5
4.0
4.5
Number of Tracks
150
100
50
0
600
500
400
300
200
100
0
Distance Along Photographic Plate (MM)
17O(d1)
29Si(d9)
17O(d0)
× 1/10
12C(d,d)
16O(d,d)
29Si(d,d)
(d,d) on Heavier Elements
13C(d0)
29Si(d5)
29Si(d4)
Silicon Dioxide Target
H = 8.229 gauss
25º Spectrum

Fig. 2



Deuteron Energy (MeV)
3.5
4.0
4.5
5.0
5.5
6.0
6.5
Aluminium Target
H = 10,140 gauss
50º Spectrum
Number of Tracks
0
100
200
300
400
500
600
Distance Along Photographic Plate (MM)
650
600
550
500
450
400
350
300
250
200
150
100
^{28}Al(d$_0$)
^{28}Al(d$_1$)
^{28}Al(d$_2$)
^{28}Al(d$_3$)
^{28}Al(d$_4$)
^{28}Al(d$_5$)
^{28}Al(d$_6$)
(d$_7$)
^{28}Al(d$_8$)
(d$_9$)
(d$_{10}$)
^{28}Al(d$_{11}$)
(d$_{12}$)
(d$_{14}$)
(d$_{15}$)
(d$_{16}$)
^{27}Al(d,d)
x 1/3

Fig. 3



$B^{10}(t,d_o)B^{11}$
Ground State
$\ell = 1$
$r_o = 5.5\times10^{-13}$cm
$B^{10}(t,d_1)B^{11}$
2.126 MeV
$\ell = 1$
$r_o = 6.5\times10^{-13}$cm
$B^{10}(t,d_2)B^{11}$
4.449 MeV
$\ell = 1$
$r_o = 5.5\times10^{-13}$cm
$B^{10}(t,d_3)B^{11}$
5.027 MeV
$\ell = 1$
$r_o = 5.5\times10^{-13}$cm
$B^{10}(t,d_4)B^{11}$
6.769 MeV
$\ell = 1$
$r_o = 5.5\times10^{-13}$cm
$B^{10}(t,d_5)B^{11}$
6.806 MeV
$\ell = 1$
$r_o = 5.5\times10^{-13}$cm
$B^{10}(t,d_6)B^{11}$
7.301 MeV
$\ell = 1$
$r_o = 5.5\times10^{-13}$cm
ANGLE IN C.M. SYSTEM (DEGREES)

Fig. 4

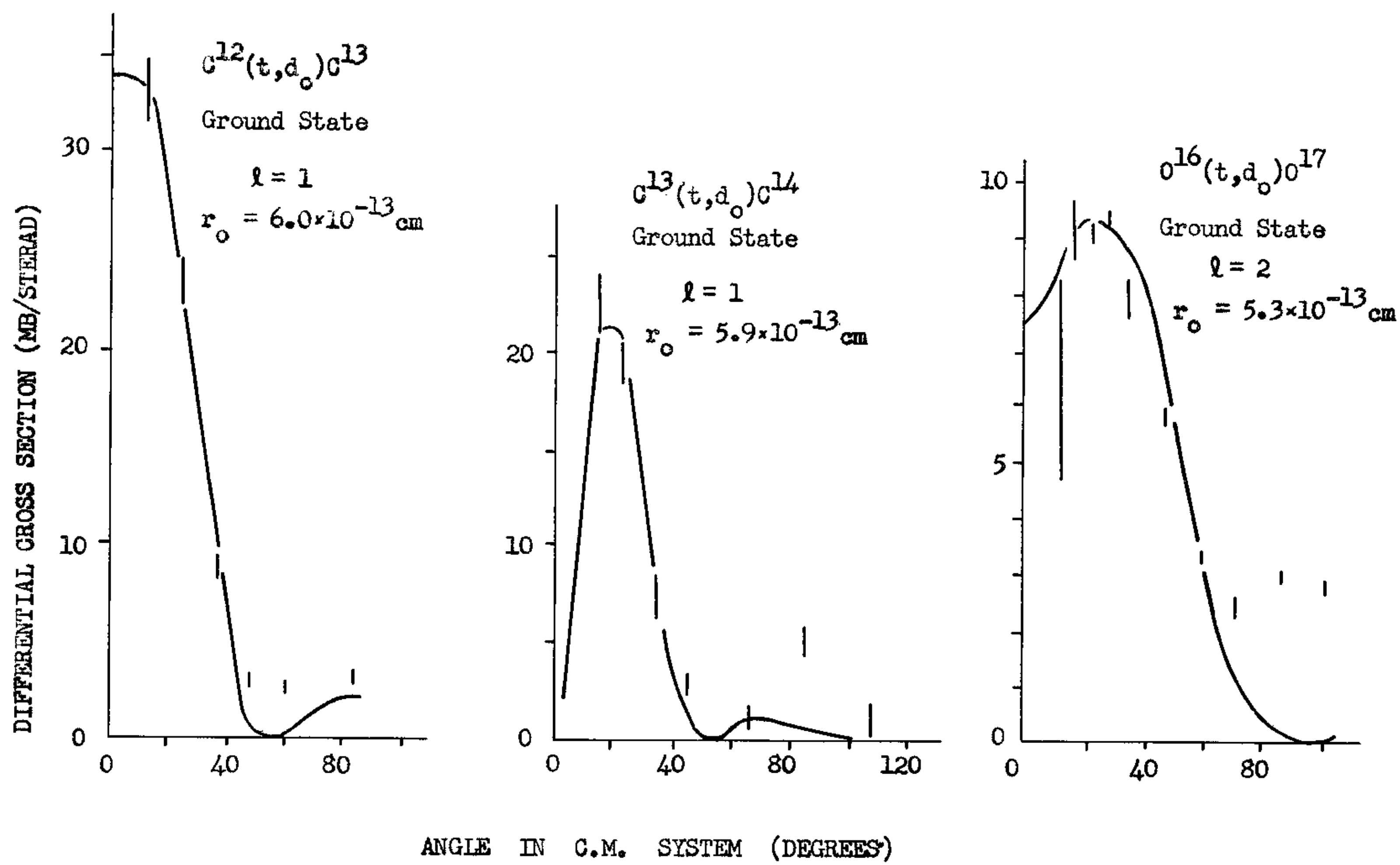
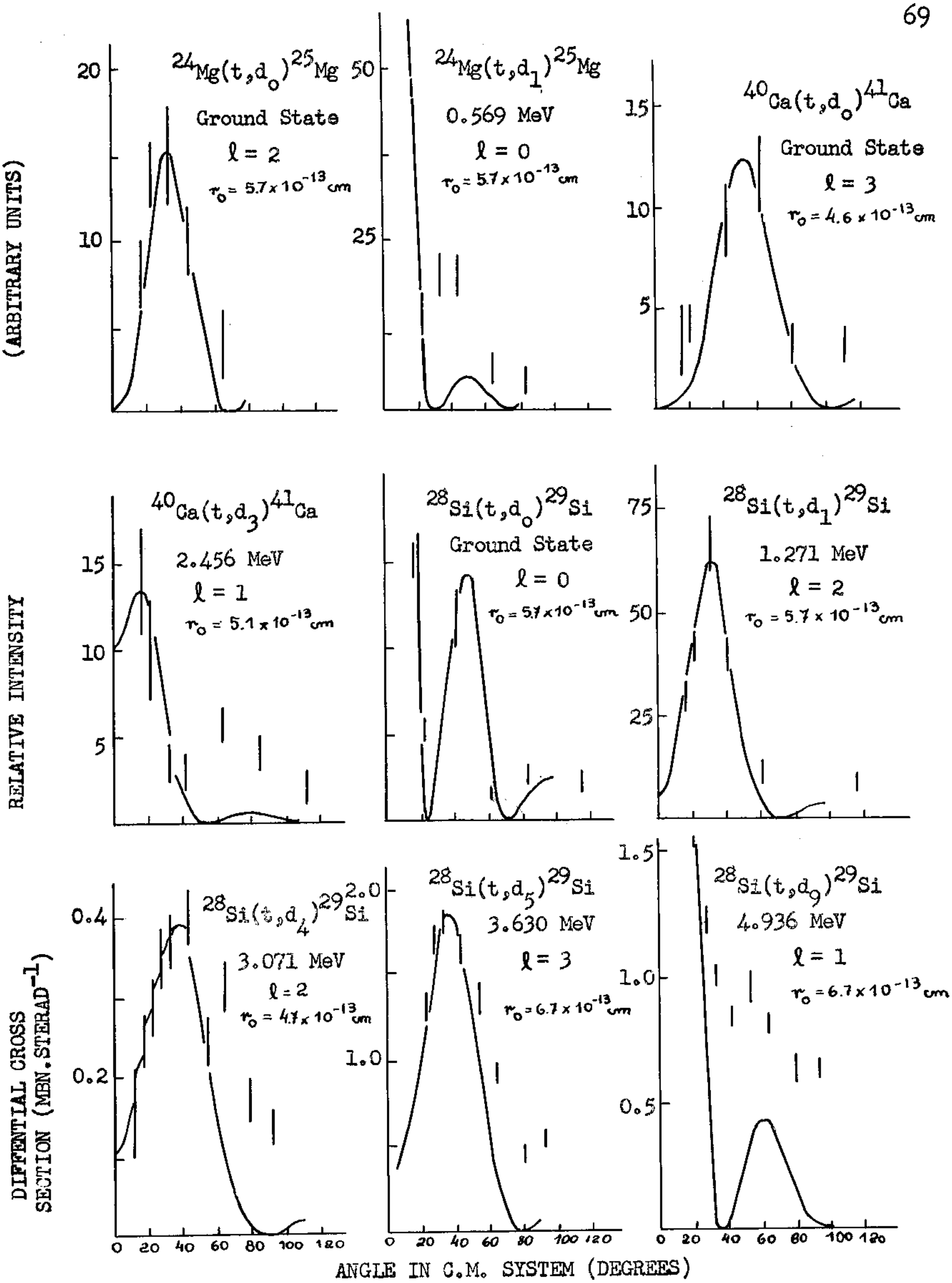
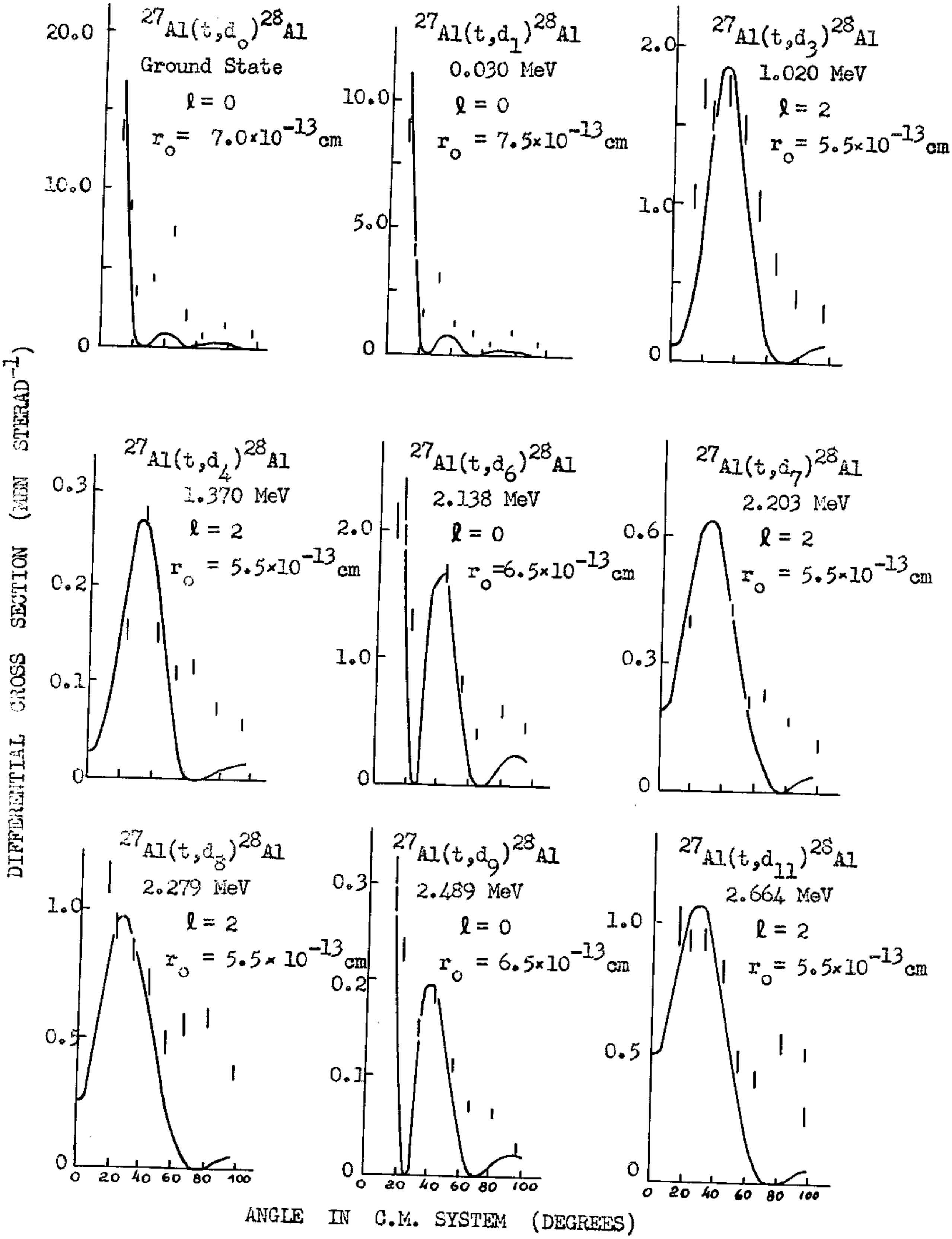

C12(t,do)C13
Ground State
ℓ = 1
ro = 6.0×10-13cm
C13(t,do)C14
Ground State
ℓ = 1
ro = 5.9×10-13cm
O16(t,do)O17
Ground State
ℓ = 2
ro = 5.3×10-13cm
DIFFERENTIAL CROSS SECTION (MB/STERAD)
0
10
20
30
0
10
20
0
5
10
0
40
80
0
40
80
120
0
40
80
ANGLE IN C.M. SYSTEM (DEGREES)

Fig. 5



(ARBITRARY UNITS)
RELATIVE INTENSITY
DIFFENTIAL CROSS SECTION (MBN.STERAD^{-1})
$^{24}Mg(t,d_o)^{25}Mg$
Ground State
$\ell = 2$
$r_o = 5.7 \times 10^{-13}$ cm
$^{24}Mg(t,d_1)^{25}Mg$
0.569 MeV
$\ell = 0$
$r_o = 5.7 \times 10^{-13}$ cm
$^{40}Ca(t,d_o)^{41}Ca$
Ground State
$\ell = 3$
$r_o = 4.6 \times 10^{-13}$ cm
$^{40}Ca(t,d_3)^{41}Ca$
2.456 MeV
$\ell = 1$
$r_o = 5.1 \times 10^{-13}$ cm
$^{28}Si(t,d_o)^{29}Si$
Ground State
$\ell = 0$
$r_o = 5.7 \times 10^{-13}$ cm
$^{28}Si(t,d_1)^{29}Si$
1.271 MeV
$\ell = 2$
$r_o = 5.7 \times 10^{-13}$ cm
$^{28}Si(t,d_4)^{29}Si$
3.071 MeV
$\ell = 2$
$r_o = 4.7 \times 10^{-13}$ cm
$^{28}Si(t,d_5)^{29}Si$
3.630 MeV
$\ell = 3$
$r_o = 6.7 \times 10^{-13}$ cm
$^{28}Si(t,d_9)^{29}Si$
4.936 MeV
$\ell = 1$
$r_o = 6.7 \times 10^{-13}$ cm
ANGLE IN C.M. SYSTEM (DEGREES)

Fig. 6



$^{27}Al(t,d_0)^{28}Al$
Ground State
ℓ = 0
$r_0 = 7.0 \times 10^{-13}$ cm
$^{27}Al(t,d_1)^{28}Al$
0.030 MeV
ℓ = 0
$r_0 = 7.5 \times 10^{-13}$ cm
$^{27}Al(t,d_3)^{28}Al$
1.020 MeV
ℓ = 2
$r_0 = 5.5 \times 10^{-13}$ cm
$^{27}Al(t,d_4)^{28}Al$
1.370 MeV
ℓ = 2
$r_0 = 5.5 \times 10^{-13}$ cm
$^{27}Al(t,d_6)^{28}Al$
2.138 MeV
ℓ = 0
$r_0 = 6.5 \times 10^{-13}$ cm
$^{27}Al(t,d_7)^{28}Al$
2.203 MeV
ℓ = 2
$r_0 = 5.5 \times 10^{-13}$ cm
$^{27}Al(t,d_8)^{28}Al$
2.279 MeV
ℓ = 2
$r_0 = 5.5 \times 10^{-13}$ cm
$^{27}Al(t,d_9)^{28}Al$
2.489 MeV
ℓ = 0
$r_0 = 6.5 \times 10^{-13}$ cm
$^{27}Al(t,d_{11})^{28}Al$
2.664 MeV
ℓ = 2
$r_0 = 5.5 \times 10^{-13}$ cm
DIFFERENTIAL CROSS SECTION (MBN STERAD^{-1})
ANGLE IN C.M. SYSTEM (DEGREES)

Fig. 7

CAPTIONS.

Figure 1. The 60° deuteron spectrum from the boron target bombarded with 5.53 MeV tritons.

Figure 2. The 25° deuteron spectrum from the silicon dioxide target bombarded with 5.53 MeV tritons.

Figure 3. The 50° deuteron spectrum from the aluminium target bombarded with 5.53 MeV tritons.

Figure 4. Angular distributions of deuteron groups from the reaction $^{10}B(t,d)^{11}B$.

Figure 5. Angular distributions of the ground state deuteron groups from the reactions $^{12}C(t,d)^{13}$, $^{13}C(t,d)^{14}C$ and $^{16}O(t,d)^{17}O$.

Figure 6. Angular distributions of deuteron groups from the reactions $^{24}Mg(t,d)^{25}Mg$, $^{28}Si(t,d)^{29}Si$ and $^{40}Ca(t,d)^{41}Ca$. Absolute cross sections were not measured for several of the transitions. In these cases the scales show the relative intensities of groups arising from the same target nucleus.

Figure 7. Angular distributions of the deuteron groups from the $^{27}Al(t,d)^{28}Al$ reaction.

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