Electrostatic Analysis of Nuclear Reaction Energies*

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Electrostatic analysis of incident and product particles has been used to measure the following reaction energies (in Mev): $D(d,H^3)p$ (4.044±0.005); $D(d,He^3)n$ (3.271±0.011); $C^{14}(d,\alpha)B^{12}$ (0.362±0.002); $C^{14}(d,p)C^{15}$ (−1.007±0.001); $B^{10}(\alpha,d)C^{12}$ (1.341±0.002); $O^{16}(d,p)O^{17*}$, 0.87 level (1.048±0.002); $N^{14}(d,p)N^{15*}$, 7.31 level (1.308±0.002); 7.58 level (1.045±0.002); 8.32 level (0.296±0.001) and 8.57 level (0.038±0.001); $C^{12}(d,p)C^{13*}$ 3.68 level (−0.960±0.002) and 3.86 level (−1.130±0.002) and $N^{14}(d,\alpha)C^{12*}$ 9.6 level (3.933±0.014). The 30-kev width of the 9.6-Mev level of C^{12} limits the spin and parity assignment to 0^+, 1^-, 2^+, or 3^-, or possibly 4^+.

I. INTRODUCTION

ACCURATE measurements of nuclear reaction energies by electrostatic deflection of incident and product particles in high-resolution cylindrical[1] and spherical analyzers[2] have been reported in previous communications.[3–7] Further reaction energies have been measured using the same equipment and procedures, except for the following modification. A proportional counter or a CsI crystal with an RCA 6199 photomultiplier were used interchangeably with the previous ZnS detector. The new detectors had a higher efficiency and improved particle discrimination.

A newly designed target holder increased the capacity from three to seven targets in addition to the beam viewing quartz used on both the older and new arrangements. Nickel target backings (2500 A) were spot welded to 5-mil nickel washers. After the target preparation they were clamped into concentrically arranged positions on the target holder.

II. TARGET PREPARATION

Thin solid targets (99% B^{10}) were prepared by evaporation of elemental boron onto the 2500-A Ni foils. Deuterium and nitrogen were gettered by titanium in an Evapor-ion pump[8] to form targets which were stable at 200°C. C^{14} targets were prepared in a discharge tube containing acetylene (enriched to 28.8% C^{14}).[9]

III. PROCEDURE

Incident particles from the electrostatic generator were selected in energy by a cylindrical electrostatic analyzer calibrated in terms of the $Li^7(p,n)Be^7$ threshold. The energy of reaction particles was determined by means of a spherical electrostatic analyzer. The spherical analyzer was again used as a secondary voltage standard because of the observed ±0.04% voltage drifts of the cylindrical analyzer. Incident particles were elastically scattered from heated platinum targets before and after the $Li^7(p,n)Be^7$ threshold as well as before and after each reaction edge for purposes of energy calibration. Errors are assigned to bombarding energies consistent with any observed shifts in the platinum scattering edges and 0.05% for the uncertainty in the absolute voltage scale.[6]

As in our earlier measurements,[2,3] angle-sensitive elastic scatterings were used to fix the angle of the outgoing to incident particle. Figure 1 shows the $D(p,p)D$

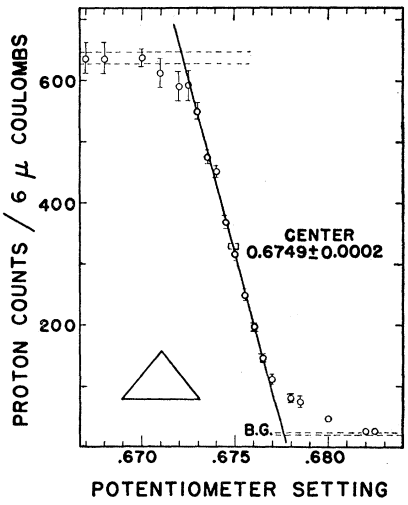

FIG. 1. High-energy edge of 2.965-Mev protons elastically scattered from deuterium. The abscissa is proportional to the energy. The base of the triangle represents the theoretical interval necessary for the yield to rise to its maximum value (twice the resolution). Uncertainty in the determination of the half-yield point is indicated by the rectangular box. B.G. represents the background.

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[1] Warren, Powell, and Herb, Rev. Sci. Instr. **18**, 559 (1947).

[2] Browne, Craig, and Williamson, Rev. Sci. Instr. **22**, 952 (1951).

[3] Williamson, Browne, Craig, and Donahue, Phys. Rev. **84**, 731 (1951).

[4] Craig, Donahue, and Jones, Phys. Rev. **88**, 808 (1952).

[5] Donahue, Jones, McEllistrem, and Richards, Phys. Rev. **89**, 824 (1953).

[6] Jones, Donahue, McEllistrem, Douglas, and Richards, Phys. Rev. **91**, 879 (1953).

[7] Jones, Douglas, McEllistrem, and Richards, Phys. Rev. **94**, 947 (1954).

[8] R. H. Davis and A. Divatia, Rev. Sci. Instr. **25**, 1193 (1954).

[9] Douglas, Gasten, and Mukerji, Can. J. Phys. (to be published).

TABLE I. Determination of the spherical analyzer angle by means of several angle sensitive reactions.

Reaction	Bombarding energy (Mev)	Angle	Uncertainty
$D^2(p,p)$	2.965	134° 27.9′	2.2′
$C^{12}(\alpha,\alpha)$	2.012	134° 29.7′	3.8′
$Li^7(d,d)$	2.012	134° 22.2′	5.0′
$Li^7(p,p)$	1.882	134° 27.9′	6.7′
Weighted mean		134° 27.0′	2.0′

edge. Table I lists the results of the angle determination

Both angle and Q-value calculations (including relativistic corrections and uncertainty calculations) were coded for an IBM 650 calculator.

Although the targets were heated to 200°C, contamination buildup was sometimes still a problem. Contamination buildup was monitored by observing the elastically scattered protons or deuterons from carbon and oxygen. Contamination corrections were less than 1 kev for all reactions except the $D(d,H^3)p$, $D(d,He^3)n$, and $N^{14}(d,\alpha)C^{12*}$ 9.6-Mev level.

IV. RESULTS

Figure 2 shows a typical reaction edge. Other edges are only shown if they require special comment.

$D(d,H^3)p$

A typical set of data on the $D(d,H^3)p$ reaction is shown in Fig. 3. The large c.m. motion makes the triton energy so angle-sensitive that the rise interval is much larger than that from instrumental resolution. Table II summarizes our results.

Our $D(d,H^3)p$ Q-value is in agreement with the California Institute of Technology[10,11] measurement but disagrees with the Massachusetts Institute of Technology[12] results. (See Table IV.) The M.I.T. target was prepared by allowing deuterium to accumulate in a thin SiO_2 layer (Pt-backed) as a result of bombardment by 1-Mev deuterons. Hence there may be some question concerning the uniformity and stability of their targets. Incident deuteron energies were measured with a magnetic analyzer and the reaction particles (protons) at 90° were measured with a second magnetic analyzer. The angle was measured geometrically rather than by an angle-sensitive elastic scattering.

The internal consistency of both the M.I.T. and the present experiments suggests that the error is a systematic one. Possible systematic errors in the M.I.T. data which could cause such a discrepancy are (a) insufficient allowance for contamination, (b) the absence of deuterium target atoms at the SiO_2 surface, or (c) an error in the angle determinations. It requires an error of only 5.6×10^{-3} radian to change the M.I.T. Q value so that it would coincide with the present determination.

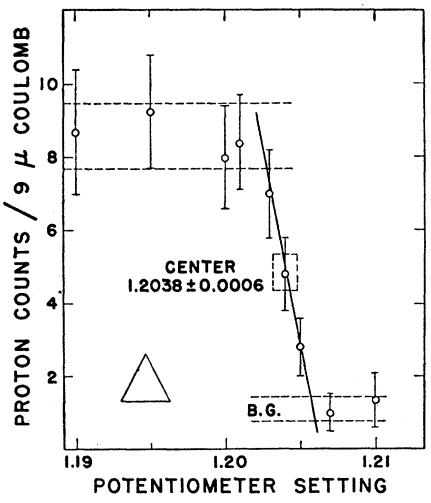

FIG. 2. A typical thick-target reaction edge: $N^{14}(d,p)N^{15*}$ 8.32 level. (See also caption for Fig. 1.)

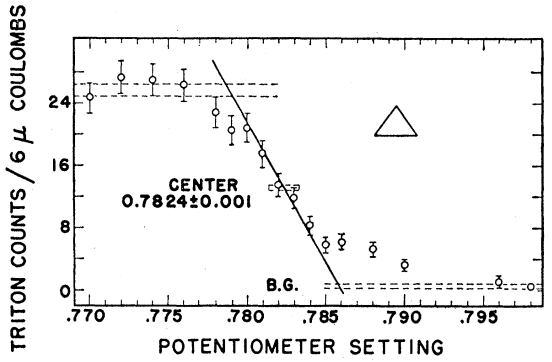

FIG. 3. High-energy edge of tritons produced in the reaction $D(d,H^3)p$. Note that the rise interval is much larger than the instrumental resolution. This effect may be caused by target inhomogeneities accentuated by the large stopping power.

Possible systematic errors in the present experiment are (a) the angle determination, and (b) the application of a contamination correction which is too large. However, the mean of our five determinations with no contamination correction is still 11 kev greater than the M.I.T. value. An error in the angle of 7.8×10^{-3} radian would be necessary to make our value coincide with that of M.I.T. This is 5.5 times greater than the largest deviation from the weighted mean of four independent angle determinations (Table I).

$D(d,He^3)n$

The large stopping power cross sections for He^3 and the kinematics of the reaction make carbon buildup layers a serious source of error. This effect was particularly important for this reaction since long bombarding times were necessitated by the low counting rate. In addition, wrinkling of the thin target backing can pro-

[10] Tollestrup, Jenkins, Fowler, and Lauritsen, Phys. Rev. **75**, 1947 (1949).

[11] Li, Whaling, Fowler, and Lauritsen, Phys. Rev. **83**, 512 (1951).

[12] Strait, Van Patter, Buechner, and Sperduto, Phys. Rev. **81**, 747 (1951).

duce large uncertainties when contamination corrections as high as 13 kev are applied to the Q value. An inspection of the used deuterium targets indicates wrinkles 1 mm across and also a distortion at the beam spot. The path length of the reaction particle in the contamination layer is doubled if the foil is inclined at 25° with the vertical and tripled if the inclination is 32°. If the foil is inclined in the opposite direction, the path length may be reduced by a factor of 0.7. The measurement of the contamination layer thickness by elastic scattering of protons from C^{12} is only increased by 10% for a 25° foil inclination. Hence, the actual contamination correction calculated in the usual manner (13 kev) can be too small by a factor of two or more.

Two determinations of the $D(d,He^3)n$ reaction energy (Table III) were obtained, but these do not agree if the ordinary correction for contamination is applied. Possibly the effect of target wrinkling is evident in these results. The reaction energy may be calculated from the $D(d,H^3)p$ data and the accurately measured[13] $H^3(p,n)He^3$ threshold. The result is 3.280±0.005 Mev. This indirect value lies between and in disagreement

TABLE II. $D(d,H^3)p$ Q values.

Bombarding energy (Mev)	Detector slit diameter (mm)	Contamination correction (Mev)	Q value (Mev)
0.3188	2	0.003	4.040±0.005
0.3187	2	0.001	4.046±0.008
0.3187	2	0.001	4.046±0.005
0.3184	4	0.004	4.043±0.006
0.4022	4	0.006	4.043±0.006
	Mean		4.044±0.005

with both the Chicago[14] and Cal. Tech.[10,14] measurements, the two most accurate direct determinations.

In both the Chicago and Cal. Tech. experiments, D_2O was continuously frozen to obtain a target which was free of contamination. It may be significant that both the Cal. Tech. $D(d,H^3)p$ and $D(d,He^3)n$ Q values are lower than the ones reported here suggesting a systematic difference. The Cal. Tech. angle was measured by means of $O^{16}(d,d)$ scattering which is considerably less angle sensitive than those used in the present experiment.

No discussion of the angle measurement is included in the Chicago paper.[14] Also the uncertainty appears to have been assigned on the basis of deviations of individual measurements from the weighted mean and would not include allowances for systematic errors.

$C^{14}(d,\alpha)B^{12}$

The Q value, 0.362±0.0015 Mev, which resulted from this measurement is in agreement with the value, 0.358±0.007 Mev, calculated from the Drummond[15] mass table. No other measurements of this Q have been reported.

[13] D. M. Van Patter and W. Whaling, Revs. Modern Phys. **26**, 402 (1954).
[14] H. Argo, Phys. Rev. **74**, 1293 (1948).
[15] J. E. Drummond, Phys. Rev. **97**, 1004 (1955).

TABLE III. $D(d,He^3)n$ Q values.

Bombarding energy (Mev)	Detector slit diameter (mm)	Contamination correction (Mev)	Q value (Mev)	Uncertainty (no wrinkling effect[a]) (Mev)	Uncertainty (with wrinkling effect) (Mev)
0.3185	2	0.007[a]	3.305	0.024	0.025
0.3184	4	0.013[a]	3.258	0.007	+0.015 −0.007
	Weighted mean		3.271		0.011

[a] The contamination correction can be too small by a factor of two or more as the result of wrinkles in the target.

$C^{14}(d,p)C^{15}$

The investigation of the extremely large discrepancy[11] between the present Q value of −1.007±0.001 Mev and the University of Texas[16] value of 0.15±0.15 Mev is described in detail elsewhere.[9] The differential cross section at 135° for this reaction corresponding to the Texas Q value was found to be less than 0.05 mb/sterad. The Texas determination has now been withdrawn.[17]

The high-energy cut-off edge of the protons (Fig. 4) shows a structure which could be explained by a 9-kev doublet in C^{15} or by a 10% increase in the C^{14} density at a depth in the target of 3 kev to 2.7-Mev deuterons. No data of sufficient accuracy were obtained to differentiate between these two possible interpretations. No other evidence for a first excited state in C^{15} was found up to an excitation energy of 500 kev. However, most of the region corresponding to the first 350-kev excitation

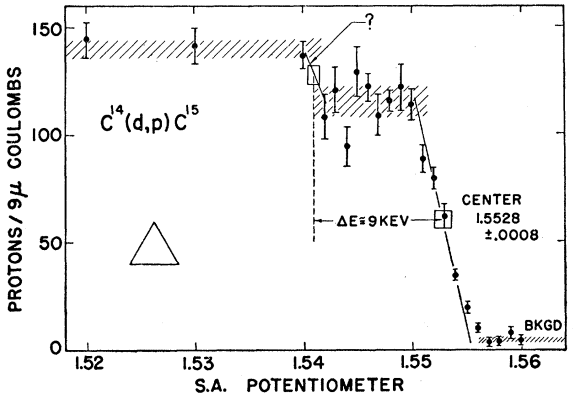

FIG. 4. $C^{14}(d,p)C^{15}$. Structure of the edge is suggested by the double set of slant lines at the top of the figure. It could be caused by a close (9-kev) doublet in C^{15} or by a 10% increase in the C^{14} density at a depth of 3 kev to the incident beam. The abscissa is proportional to the proton energy. BKGD represents the background.

[11] *Note added in proof.*—Professor S. K. Allison (private communication) reports a $C^{14}(d,p)C^{15}$ Q value of −1.06±0.05 Mev based on measurements by his group of the $Be^9(Li^7, p)C^{15}$ reaction Q value.
[16] Rickard, Hudspeth, and Clendenin, Phys. Rev. **96**, 1272 (1950).
[17] Bostrom, Hudspeth, and Morgan, Bull. Am. Phys. Soc. Ser. II, **1**, 94 (1956).

TABLE IV. Results of Q value measurements and comparison with those of other laboratories.

Reaction (excited state levels in Mev)	Q (Mev)	Other determinations (Mev)	Laboratory
$D(d,H^3)p$	4.044±0.005	4.030±0.006	M.I.T.[a]
		4.036±0.012	Cal. Tech.[b]
$D(d,He^3)n$	3.271±0.011	3.265±0.009	Cal. Tech.[b]
		3.30 ±0.010	Chicago[c]
		3.280±0.005	Reaction cycle[d]
$C^{14}(d,\alpha)B^{12}$	0.362±0.0015	0.359±0.007	Reaction cycle[e]
$C^{14}(d,p)C^{15}$	−1.007±0.001	0.15 ±0.15	Texas[f]
$B^{10}(\alpha,d)C^{12}$	1.341±0.001	1.39 ±0.01	Cavendish[g]
		1.344±0.011	Reaction cycle[h]
		1.335±0.013	Reaction cycle[i]
$O^{16}(d,p)O^{17*}$, 0.87 level	1.048±0.002	1.049±0.007	M.I.T.[j]
		1.040±0.010	M.I.T.[k]
$N^{14}(d,p)N^{15*}$, 7.31 level	1.308±0.0015	1.301±0.010	M.I.T.[k]
		1.306±0.005	M.I.T.[l]
7.57 level	1.045±0.0015	1.040±0.010	M.I.T.[k]
8.32 level	0.296±0.001	0.299±0.010	M.I.T.[k]
		0.300±0.005	M.I.T.[l]
8.58 level	0.038±0.001	0.044±0.010	M.I.T.[k]
$C^{12}(d,p)C^{13*}$, 3.68 level	−0.960±0.002	−0.967±0.008	M.I.T.[k]
3.86 level	−1.130±0.002	−1.138±0.007	M.I.T.[k]
$N^{14}(d,\alpha)C^{12*}$, 9.6 level	3.933±0.014	3.955±0.003	M.I.T.[m]

[a] See reference 12.
[b] See references 10 and 11.
[c] See reference 14.
[d] $D(d,H^3)p$ (present work) and $H^3(p,n)He^3$ (reference 13).
[e] $C^{13}(d,p)C^{14}$, $C^{13}(d,\alpha)B^{11}$, and $B^{11}(d,p)B^{12}$ (see reference 13).
[f] See reference 16.
[g] See reference 18.
[h] $C^{12}(d,p)C^{13}$ (reference 13) and $C^{13}(p,\alpha)B^{10}$ [Fades, private communication to A. H. Wapstra, Physica **21**, 367 (1955)].
[i] $C^{13}(d,\alpha)B^{11}$, $C^{12}(d,p)C^{13}$ (reference 13) and $B^{10}(d,p)B^{11}$, R. B. Elliott and D. J. Livesey, Proc. Roy. Soc. **224**, 124 (1954).
[j] Buechner, Strait, Sperduto, and Malm, Phys. Rev. **76**, 1543 (1949).
[k] See reference 20.
[l] R. Malm and W. W. Buechner, Phys. Rev. **80**, 771 (1950).
[m] R. Malm and W. W. Buechner, Phys. Rev. **81**, 519 (1951).

was obscured by proton groups from the $C^{12}(d,p)C^{13*}$ 3.68- and 3.86-Mev levels. At 135° and 2.5-Mev bombarding energy, the intensity of a group corresponding to the region of 350- to 500-kev excitation in C^{15} would be less than 5% of the ground state reaction intensity.

$B^{10}(\alpha,d)C^{12}$

Table IV gives the comparisons of this Q value with other determinations. It is in disagreement with the work of Shire *et al.*[18] but agrees with the results obtained from the two most accurate reaction cycles available.

$O^{16}(d,p)O^{17*}$. 0.87-Mev Level

The target used for this reaction was one which had been prepared for nitrogen work and oxygen was present as a reasonably abundant contaminant. The structure displayed in Fig. 5 could be interpreted as exhibiting target structure, the effect of a group of particles from a contaminant in the target, or an 11-kev doublet in O^{17}. Insufficient data were obtained to differentiate between these explanations.¶ If a doublet is assumed, the Q values of the two edges are 1.048±0.002 and 1.037±0.003 Mev. The excitation energies in O^{17} would be 0.871±0.004 and 0.882±0.005 Mev if a Q value[13] of 1.919±0.004 Mev is taken for the ground state reaction. It may be worth pointing out that such a close doublet in O^{17} would reconcile the discrepancy between the Cal. Tech. γ-ray measurement of this level (870.5±2 kev)[19] and the best M.I.T. particle data (880±5 kev).[20] Likewise it would give a simple explanation of the two close neutron thresholds seen at Rice

[18] Shire, Wormald, Lindsay-Jones, Lunden, and Stanley, Phil. Mag. **44**, 1197 (1953).

¶ *Note added in proof.*—The target was 15 kev thick for the incident deuterons, and 25 kev thick for the emergent protons, while the instrumental resolution was about 4 kev. Thus an oxygen layer on the rear of the target could not produce the observed effect. Assuming the O^{17} doublet to be real, the protons due to these states had energies of 1.667 Mev and 1.677 Mev, respectively, for E_d=0.998 Mev and θ_{lab}=134° 27′. These protons were clearly distinguished from the closest known contaminant group, namely, 1.630 Mev protons from the reaction $N^{14}(d,p)N^{15*}$ 7.58 Mev level.

[19] R. G. Thomas and T. Lauritsen, Phys. Rev. **88**, 969 (1953).

[20] Sperduto, Buechner, Bockelman, and Browne, Phys. Rev. **96**, 1316 (1954).

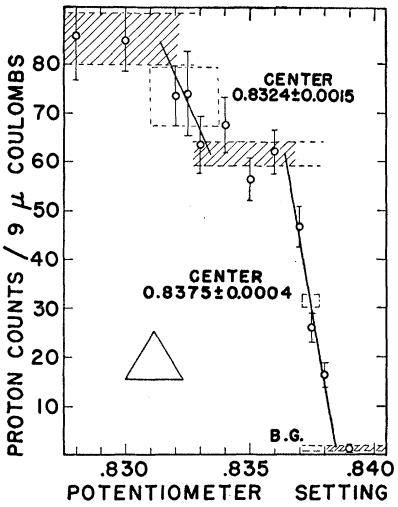

FIG. 5. $O^{16}(d,p)O^{17*}$ 0.87-Mev level. Structure of the edge could be caused by a close doublet in O^{17*}, the effect of a proton group from a target contaminant or a sudden 35% increase in the O^{16} density at a depth of 6 kev to the incident beam.

Institute[21] in the mirror reaction $O^{16}(d,n)F^{17*}$ and perhaps also reconcile the γ-ray measurements for F^{17*} (0.487 ± 0.015 Mev)[22] and the neutron measurements of Ajzenberg[23] ($E_x=0.536\pm0.010$ Mev).

$N^{14}(d,p)N^{15*}$. 7.31-, 7.57-, 8.32-, and 8.58-Mev Levels

Q values to four excited states of N^{15} have been measured. Table IV shows a comparison of these results with the measurements of other laboratories. Recent pair spectrometer measurements at Chalk River[24] have revised earlier determinations[25] of the $N^{14}(n,\gamma)N^{15*}$ gamma-ray energies. Now there is agreement among all the measurements [assuming that the $N^{14}(d,p)N^{15}$ ground-state $Q=8.614\pm0.007$ Mev[13]]. Also the M.I.T. group[20] quotes 0.263 ± 0.005 and 0.258 ± 0.004 Mev for the energy separation from the 7.31 to 7.57 and 8.32 to 8.58 Mev levels, respectively. Our corresponding values are 0.263 ± 0.001 and 0.258 ± 0.001 Mev.

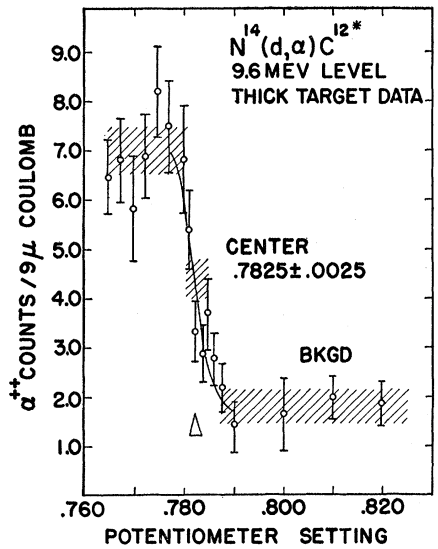

FIG. 6. $N^{14}(d,\alpha)C^{12*}$ 9.6-Mev level. This target produced typical thick-target yield curves for other N^{14} reactions. Hence the long rise interval is attributed to the width of the 9.6-Mev level in C^{12}.

[21] Marion, Brugger, and Bonner, Phys. Rev. **100**, 46 (1955).
[22] Warren, Laurie, James, and Erdman, Can. J. Phys. **32**, 563 (1954).
[23] Fay Ajzenberg, Phys. Rev. **83**, 693 (1951).

$C^{12}(d,p)C^{13*}$. 3.68- and 3.86-Mev Levels

The present experiment gives Q values of -0.960 ± 0.002 and -1.130 ± 0.002 Mev, respectively, for reactions leading to the second and third excited states of C^{13}. These Q's are in agreement with the M.I.T. values. The separation between these two levels in C^{13} quoted by the M.I.T. group as 0.170 ± 0.003 Mev is also in excellent agreement with the present determination of 0.170 ± 0.0015 Mev.

TABLE V. Calculated maximum widths (in Mev) of the 9.6-Mev level of C^{12*} corresponding to the Wigner limit on reduced widths. Three different interaction radii were considered. (The observed width is 0.030 ± 0.008 Mev.)

l wave \ a (cm)	5.8×10^{-13}	5.0×10^{-13}	4.5×10^{-13}
S	2.26	2.05	2.00
P	1.61	1.44	1.40
D	0.94	0.63	0.49
F	0.31	0.16	0.10
G	0.058	0.022	0.011

$N^{14}(d,\alpha)C^{12*}$. 9.6-Mev Level

Figure 6 shows the edge obtained with the same thick TiN target which was used for the $N^{14}(d,p)N^{15*}$ reaction (Fig. 2). One notes that for the (d,α) reaction the rise interval is large compared to the instrumental resolution (indicated by Δ on the figures), whereas for the (d,p) reaction (Fig. 2), the observed rise interval matched the instrumental resolution. The large rise interval implies that the unbound residual state in C^{12} ($E_x=9.6$ Mev) has a natural width large compared to our instrumental resolution. Very-thin-target data (not shown) confirmed this interpretation since the half-width of the thin-target data matched the rise interval of Fig. 6 within the rather large statistical uncertainty of the thin-target data. The half-yield point of Fig. 6 gives a $Q=3.933\pm0.014$ Mev in good agreement with the Q calculated from the peak of the thin-target data: $Q=3.933\pm0.020$ Mev. The thick-target data are not quite in agreement with the M.I.T.[26] value of 3.955

[24] P. J. Campion and G. A. Bartholomew, Bull. Am. Phys. Soc. Ser. II, **1**, 28 (1956), and private communication.
[25] Kinsey, Bartholomew, and Walker, Can. J. Phys. **29**, 1 (1951).
[26] R. Malm and W. W. Buechner, Phys. Rev. **81**, 519 (1951).

± 0.003 Mev. In the M.I.T. experiment with a N^{15}-enriched target, this alpha group was not resolved from the overlapping alpha group expected from the $N^{15}(d,\alpha)C^{13*}$ (3.86-Mev level). A serious systematic error may therefore exist in the M.I.T. data.

An experimental width ($\Gamma_{c.m.}$, the width at half-height) of 30 kev for the 9.6-Mev level in C^{12} was calculated from the energy distribution of the alpha particle whose energy in the recoiling center-of-mass system is (8/12) (2.27 Mev). Therefore, from the conservation of angular momentum and parity, one can restrict the spin and parity assignment to the following values: 0^+, 1^-, 2^+, 3^-, 4^+, 5^- etc. A limit may be placed upon this series through use of the Wigner limit,[27] since the reduced width $\gamma^2 \leq \frac{3}{2}(\hbar^2/\mu a)$, where a is the interaction radius. Calculated widths corresponding to the maximum allowed reduced width are given in Table V for three different interaction radii. Coulomb penetrabilities were obtained from tables compiled at Chalk River.[28] These widths are to be compared to the experimental determination of 0.030 ± 0.008 Mev. It can be seen that l waves of 3 or less (and hence J values of 3 or less) are allowed, 4 implies maximum reduced width and higher l values would be forbidden.

ACKNOWLEDGMENTS

We wish to thank Professor H. T. Richards for suggesting this work and for many helpful discussions in it. Professor Herb kindly allowed us the use of an Evaporion pump for the preparation of nitrogen and deuterium targets.

[27] R. G. Sachs, *Nuclear Theory* (Addison-Wesley Publishing Company, Cambridge, 1953), p. 310.

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Study of the Reaction Mechanism for (He^3,p) Reactions with Li^6, B^{10}, and C^{13}†

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Excitation curves and angular distributions have been obtained for five (He^3,p) reactions in which the initial and final states were of known spins and parities. The results give information on the reaction mechanisms involved. All the reactions studied showed resonances in the excitation curves indicating that the reactions proceeded at least in part by way of a compound system. In one or possibly two cases, the angular distributions showed a strong asymmetry about 90°, suggesting the admixture of some other reaction mechanism.

INTRODUCTION

IN recent years considerable attention has been given to nuclear reaction mechanisms which by-pass the formation of a compound nucleus. Theoretical calculations[1] have been conspicuously successful in interpreting experimental data for deuteron-induced reactions on light elements, where, for bombarding energies of from 1 to 15 Mev, both protons and neutrons exhibit angular distributions that cannot be explained in terms of compound-nucleus formation. On the other hand, reactions induced by protons and alpha particles in this energy range yield angular distributions which are generally consistent with compound-nucleus formation. Reactions induced by bombardment with H^3 and He^3 ions have produced inconclusive results. While some experiments[2] apparently show marked and consistent asymmetries about 90° that are somewhat similar to those observed in deuteron reactions, others[3] indicate resonances in yield and variations in angular distributions with energy which can only be associated with levels in the compound nucleus.

The recent availability of comparatively large quantities of He^3 has made possible the acceleration of He^{3+} ions in the Rice Institute Van de Graaff accelerator. With a view towards studying the reaction mechanisms involved, excitation functions and angular distributions were obtained in the energy range of 1 to 5 Mev for several reactions involving initial and final states of known spins and parities.

EXPERIMENTAL PROCEDURE

The angular distribution chamber used in this experiment has been described previously.[4] Holes of $\frac{1}{4}$-inch diameter at 10° intervals on a 5-inch diameter cylinder

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