Reaction $C^{12}(\alpha,d)N^{14}$†

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The energy spectra of deuterons from the reaction $C^{12}(\alpha,d)N^{14}$ have been measured. The reaction was induced by 47.5-Mev helium ions. Angular distributions are given for the deuteron groups corresponding to formation of the ground state and 3.95-Mev level of N^{14}.

Formation of the 2.31-Mev 0+, $T=1$ level of N^{14} was not observed; the cross section was less than 3% of the cross section for formation of the 1+, $T=0$ ground state. It is suggested that this cannot be interpreted as strong evidence for the conservation of isotopic spin for two reasons. First, several well-known $T=0$ levels were not populated to an observable extent. Second, the reaction leading to the $T=1$ level would involve a transition from a 0+ level to a 0+ level, and such transitions in (α,d) or (d,α) reactions involve difficulties with angular momentum and parity conservation in addition to nonconservation of isotopic spin, which requires $\Delta T=0$.

INTRODUCTION

SIMPLE direct nuclear reactions that involve the transfer of a single nucleon now appear to be fairly well understood. Tobocman,[1] for example, has found that calculations using a distorted-wave Born approximation with optical potentials can give angular distributions for (d,p) reactions in good agreement with experiment even for target nuclei as heavy as Pb^{208}. Reactions involving the transfer of more than a single nucleon have, by comparison, been neglected. The (d,α) and (α,d) reactions have been studied in a few cases,[2–18] but complete angular distributions are uncommon. In many cases, interest was centered on the observation of energy levels of the product nucleus. Many references to experiments of this kind have been given by Ajzenberg-Selove and Lauritsen.[19] If nuclear forces are charge-independent, (α,d) and (d,α) reactions can lead only to final states that have the same isotopic spin as the target nucleus,[20] and several (d,α) reactions have been studied from this point of view.

In the stripping (α,d) reaction, the incident helium ions lose two nucleons to the target nucleus. If the helium ion breaks up into two deuterons, one of which is captured by the target, then the captured nucleons are in a relative $^3S_1$ state unless the interaction potential causes the spin of one of the nucleons to flip. The states of the final nucleus most likely to be formed are perhaps those in which the captured proton and neutron have the same angular momentum. If the captured nucleons cannot enter equivalent states (for example, if the target is a heavy nucleus with widely different proton and neutron numbers), then the cross section for the (α,d) reaction may be small.

When conservation of angular momentum and parity permits a direct nuclear reaction to occur with more than one allowed value of the orbital angular momentum L of the captured particle, it is generally observed that the angular distribution of the outgoing particle corresponds to the lowest L value. In some cases, however, the shell-model description of the final state requires that L should be greater than the lowest permitted value.[21] In the reaction $C^{12}(\alpha,d)N^{14}$ (ground state), the captured proton and neutron are both entering the $p_{\frac{1}{2}}$ shell, and if they are captured in a relative $^3S_1$ state, $L=2$ should predominate over $L=0$, because the $^3D_1$ term is dominant in the $L-S$ expansion of the $(p_{\frac{1}{2}})^2{}_{J=1}$ wave function. This point is discussed in more detail below. The present experiment was undertaken as part of an investigation of these, and other, aspects of the (α,d) reaction.

EXPERIMENTAL

Bombardments were made with the deflected external beam of the Crocker Laboratory 60-inch cyclotron, using approximately 48-Mev helium ions. The beam

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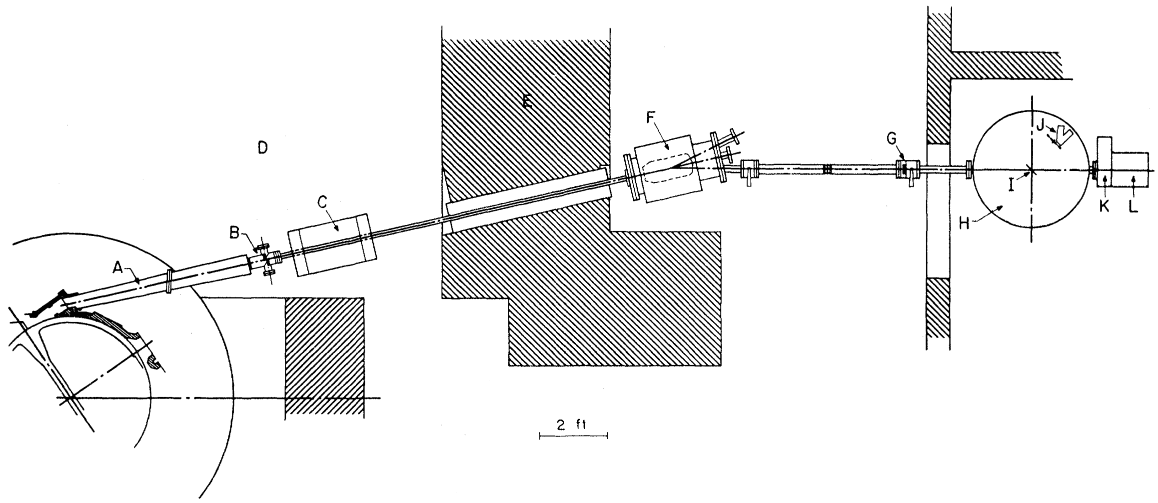

FIG. 1. Experimental arrangement. *A*, iron pipe; *B*, adjustable slit; *C*, quadrupole focusing magnet; *D*, cyclotron vault; *E*, shielding wall; *F*, steering magnet; *G*, $\frac{3}{16}$-in.-diameter collimator; *H*, 36-inch scattering chamber; *I*, target; *J*, counter and foil wheel; *K*, foil wheel for measuring beam energy; and *L*, Faraday cup.

was brought through a quadrupole focusing magnet, a small steering magnet, and a $\frac{3}{16}$-inch diameter graphite collimator into a 36-inch diameter scattering chamber.[22] The arrangement of this equipment is shown in Fig. 1.

Particles were detected by means of a counter telescope that measured dE/dx in a 0.010-inch thick CsI(Tl) crystal, and E in a $\frac{1}{2}$-inch thick NaI(Tl) crystal. Identification of the particle type was made by means of a Los Alamos-type pulse multiplier[23] which operated on the dE/dx and E pulses. A block diagram of the counting equipment is shown in Fig. 2. Multiplied pulses corresponding to deuterons were used to trigger a Penco 100-channel pulse-height analyzer, which recorded the energy spectrum of deuterons.

The analyzer was modified by the installation of a variable upper discriminator in addition to the standard lower discriminator. The energy of a particle was thus recorded only when the coincident pulse from the pulse multiplier fell between the upper and lower discriminator voltages, which were set to correspond to deuterons.

The magnet regulator of the 60-inch cyclotron produces large electrical disturbances lasting about 20 μsec, with a repetition rate of 360 cps. The magnet-regulator anticoincidence circuit picked up these and other noise signals with an antenna, and gated off the pulse-height analyzer for the duration of the noise pulse.

An event was recorded by the analyzer only when three requirements were satisfied:

(a) The pulse from the multiplier corresponded to a deuteron,

(b) the "*E*-signal coincidence circuit" supplied a pulse above a predetermined size to the coincidence unit, and

(c) the coincidence unit received no pulse from the magnet-regulator anticoincidence circuit. Requirement (b) was most useful when the pulse-height analyzer was used to record the pulse-height spectrum from the pulse multiplier. By varying the discriminator setting in the *E*-signal coincidence circuit, the effect of particle energy on the multiplied pulse spectrum could be investigated.

The counter telescope could be rotated to any desired angle within the scatter chamber, but measurements at angles smaller than 8 deg (laboratory system) were not possible because the edge of the counter intercepted part of the helium ion beam. A foil wheel was placed immediately in front of the counter entrance collimator. At small angles, an absorber thick enough to stop the elastically scattered helium ions was used. At larger angles, the absorber was progressively removed, reaching 0 at 45 deg.

Figure 3 shows a typical spectrum of pulses from the pulse multiplier. The particles originated from the bombardment of carbon with 48-Mev helium ions. This system produces a relatively large number of protons, but almost no tritons. A Teflon target provided a convenient source of protons, deuterons, and tritons in comparable yields from the reaction of helium ions with F^{19}, and such targets were frequently used in making preliminary adjustments of the pulse multiplier.

The beam intensity was measured by means of a Faraday cup and integrating electrometer. Helium ions elastically scattered from the target at a fixed

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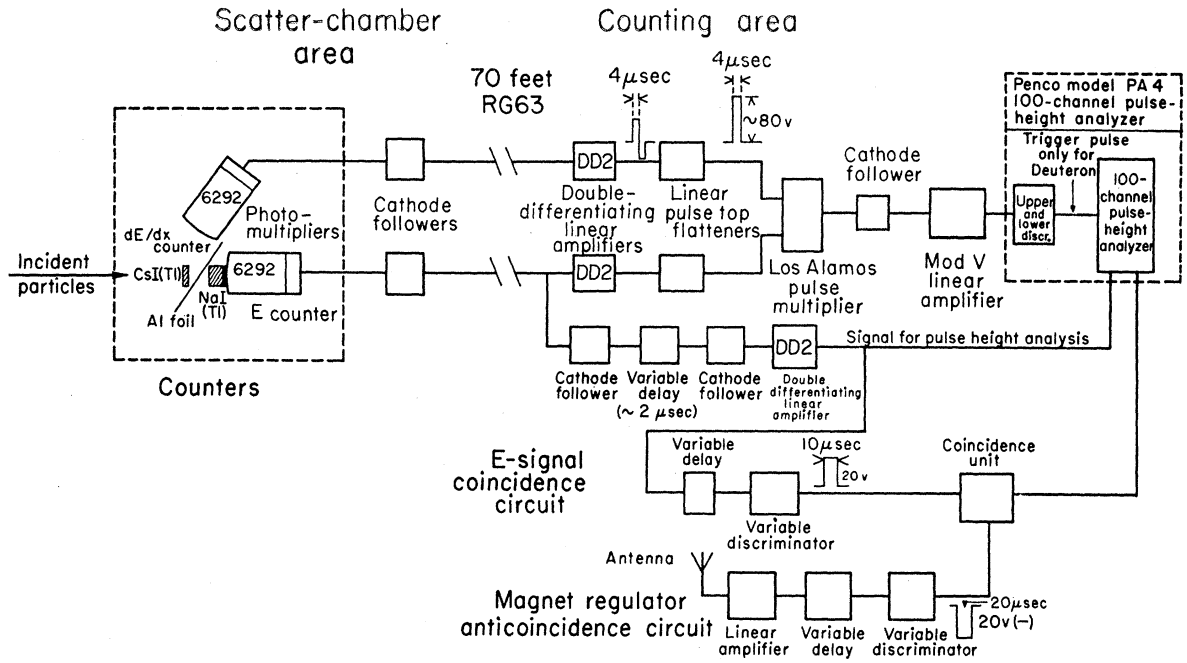

FIG. 2. Block diagram of counting equipment for recording deuteron energy spectra.

angle (20 deg) were measured with a CsI(Tl) crystal detector to provide a continuous check of the thickness of the target. The carbon targets were found to be stable.

The helium ion energy was measured by means of an absorber wheel placed in front of the Faraday cup. Ranges in aluminum were converted into energy by means of helium ion range-energy tables calculated[24] from the experimental proton ranges in aluminum measured by Bichsel, Mozley, and Aron.[25] The E counter was calibrated with cyclotron-accelerated deuterons which were elastically scattered from the target. The energy of the deuterons was calculated from the energy of the cyclotron helium ion beam.

Carbon targets were prepared by carbonizing circles of Whatman filter paper clamped between two graphite blocks. Targets made in this way were very uniform and quite easy to handle. In a preliminary run, a deuteron peak attributable to $O^{16}(\alpha,d)F^{18}$ (ground state) was observed. The oxygen impurity was removed almost completely from the targets by heating them to 1400°C for several hours in a vacuum, and allowing them to cool completely before exposure to air. However, a residual trace of the unwanted deuteron group remained, and was not reduced by a second vacuum-furnace treatment of the targets. The thickness of the targets was measured by weighing a known area of the foils. Two foils were used together, giving a total target thickness of 3.57 mg/cm^2.

[24] Robert E. Ellis, Robert G. Summers-Gill, and Franklin J. Vaughn (private communication to Homer E. Conzett).

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RESULTS

Figure 4 shows a typical energy spectrum of deuterons from the reaction $C^{12}(\alpha,d)N^{14}$ measured at 60 deg. The calculated deuteron energies shown in Fig. 4 were obtained as a function of angle for the ground-state and 3.95-Mev levels of N^{14} from the Q value given by Ashby and Catron,[26] using an IBM 650 computer program.

The angular distribution of deuterons corresponding to formation of the ground state of N^{14} is shown in Fig. 5. The errors shown represent counting statistics only. The accuracy of the angular scale is about ± 1 deg. The points shown in Fig. 5 represent measurements from three separate runs spaced several months apart. They have not been normalized. The cross section integrated between 10 and 133 deg is 1.8 mb.

At no angle was it possible to distinguish a deuteron group corresponding to formation of the $T=1$ first excited state of N^{14} at 2.31 Mev. Unfortunately, a small deuteron group probably due to oxygen impurity in the target obscured the position of the $T=1$ state at some angles and contributed to a small flat background at others; in spite of this, the upper limit of the cross section for formation of the state can be set at about 3% of the cross section for formation of the ground state.

The angular distribution of deuterons corresponding to formation of the 3.95-Mev second excited state of N^{14} is shown in Fig. 6. Because the separation of this low-intensity group from others was difficult, the

[26] Val J. Ashby and Henry C. Catron, Lawrence Radiation Laboratory Report UCRL-5419, February 10, 1959 (unpublished).

accuracy of the points is probably only about ±20%. The cross section integrated between 10 and 90 deg is 0.36 mb.

At angles greater than 45 deg, where the thickness of the absorber in front of the counter was 0, several additional deuteron groups of lower energy were observed. The corresponding N^{14} level energies were calculated from the deuteron energy spectra at 45, 50, 52.5, 55, 57.5, and 60 deg as follows. The energy differences between peaks were obtained from the cyclotron-accelerated deuteron energy calibration of the E counter. These differences were converted to energy separations between levels; the absolute level energies were then obtained by normalizing to an energy of 3.95 Mev for the second excited state of N^{14}. The observed deuteron groups correspond to the level energies of N^{14} shown in Table I. The errors are the mean deviations from the mean of six determinations. Although many known levels are listed in Table I as unobserved, it is obvious from a study of the spectrum shown in Fig. 4 that the energy resolution was not high enough to permit low limits to be set for the cross sections of the reactions populating these levels. The most striking feature of the energy spectrum is the large "hole" that occurred for N^{14} excitation energies between 6.24 and 8.84 Mev.

DISCUSSION

Failure to observe the 2.31-Mev $T=1$ level of N^{14} should not be interpreted as strong evidence for the conservation of isotopic spin. The (α,d) reaction appears to be rather selective in the choice of levels. For example, there are nine known levels in the energy interval between 6.23 and 8.99 Mev, and although three of them are believed to be $T=0$ levels, they were not observably populated.

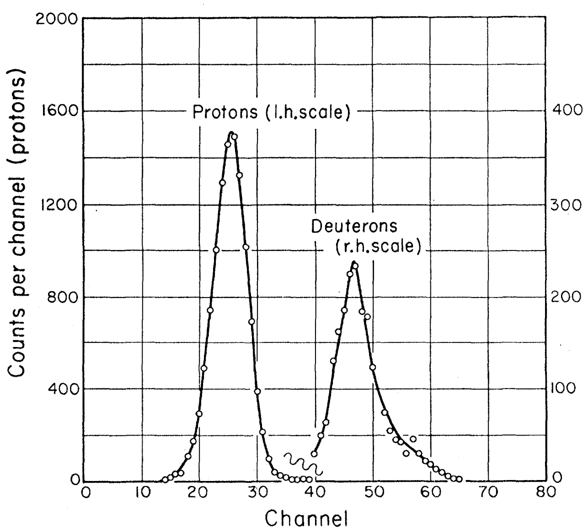

FIG. 3. Pulse-multiplier spectrum from bombardment of C^{12} with 47.5-Mev helium ions.

TABLE I. Comparison of N^{14} levels observed in this experiment with those previously reported.[a]

Measured energy	N^{14} level energies (Mev) Previously reported levels: Energy	J	π	T
0.25±0.09	0	1	+	0
...	2.312	0	+	1
3.95	3.945	1	+	0
5.11±0.12	4.910	(0)	(−)	0
	5.104	2	(−)	0
5.77±0.18	5.685	1	(−)	0
	5.832	3	(−)	?
6.24±0.12	6.23	1	(−)	0
...	6.44	(3)	?	0
...	7.03	(2)	?	0
...	7.40	?	?	?
...	7.60	?	?	?
...	7.962	?	?	0
...	8.060	1	−	1
...	8.62	0	+	1
...	8.71	0	−	1
...	8.903	3	−	(1)
8.84±0.16[b]	8.99	(1)	(+)	?
	9.17	(2,1)	(+)	1

[a] See references 19, 27.
[b] The observed level at 8.84 Mev is assigned in Table I to the known level at 8.99 Mev rather than to the closer levels at 8.71 and 8.90 Mev, because these two levels are believed to be $T=1$. The isotopic spin of the 8.99-Mev level has not been reported; if our assignment is correct, this is a $T=0$ level.

Small cross sections for the formation of low-lying $T=1$ levels have been observed in the reactions $O^{16}(d,\alpha)N^{14}$,[6,14] $Si^{28}(d,\alpha)Al^{26}$,[7,18] $S^{32}(d,\alpha)P^{30}$,[8] and $Ca^{40}(d,\alpha)K^{38}$.[9] The 1.74-Mev $T=1$ level of B^{10} was not observed in the reaction $C^{12}(d,\alpha)B^{10}$, but the detection efficiency was not high.[28]

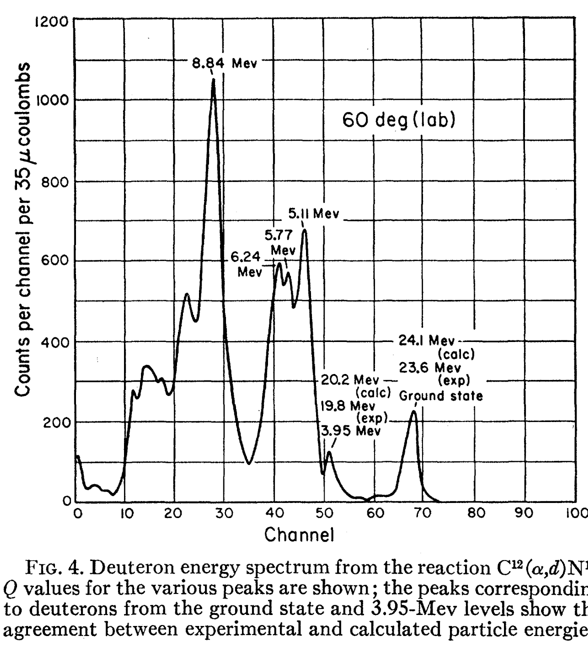

FIG. 4. Deuteron energy spectrum from the reaction $C^{12}(\alpha,d)N^{14}$. Q values for the various peaks are shown; the peaks corresponding to deuterons from the ground state and 3.95-Mev levels show the agreement between experimental and calculated particle energies.

[27] E. K. Warburton, H. G. Rose, and E. N. Hatch, Phys. Rev. **114**, 214 (1959).
[28] F. A. El Bedewi and I. Hussein, Proc. Phys. Soc. (London) **A70**, 233 (1957).

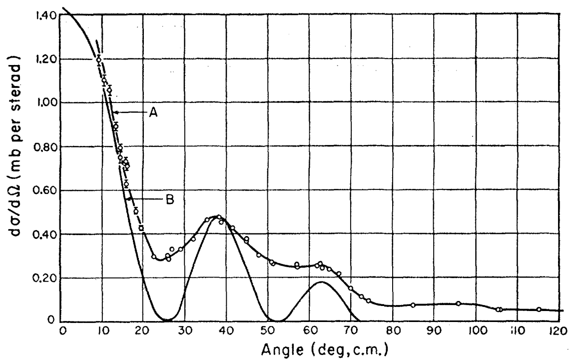

FIG. 5. Angular distribution of deuterons from formation of the ground state of N^{14}. Curve A presents the experimental results; Curve B, calculated results from the Butler equation using $l=2$, $r=6.3$ fermis.

The conservation of angular momentum requires that the capture of a spin 1 particle in a $J=0$ target nucleus can only produce a $J=0$ final state if L, the orbital angular momentum of the particle, is 1. However, if the initial and final states have the same parity, then capture of a particle with odd L is forbidden. For example, stripping of a triplet-state proton-neutron pair from a helium ion and its capture by a $J=0+$ target nucleus cannot lead to the formation of a $J=0+$ final state. In the low-lying levels of light odd-odd nuclei, in which the odd proton and neutron are in equivalent states and the even-even core is undisturbed, $0+$ levels are necessarily $T=1$, and hence the difficulties with angular momentum and parity conservation in a $0+\rightarrow 0+(\alpha,d)$ transition are in this case identical with the difficulty of isotopic spin conservation. For states of more complex character at higher excitation energies, the requirements of angular momentum and parity conservation still make formation of $0+$ levels impossible even though Coulomb forces and level mixing may have caused isotopic spin to be no longer a good quantum number.

The $0+\rightarrow 0+(d,\alpha)$ or (α,d) reactions are not forbidden by angular momentum and parity conservation when the mechanism involves the formation of a compound nucleus. The only requirement is that the orbital angular momenta of the incident and outgoing particles be equal. The angular distribution of the emitted particles should be symmetric about 90 deg. However, Hashimoto and Alford pointed out that in a (d,α) reaction with a spin $0+$ target, compound states of spin $j=l_d$, $l_d\pm 1$ and parity $(-)^{l_d}$ are formed, and of these only one third (the states of spin l_d) can decay by alpha emission to a $0+$ final state.[9] They found that the reaction $Ca^{40}(d,\alpha)K^{38}$ ($0+$, $T=1$ state at 123 kev) with approximately 4-Mev deuterons was hindered by a factor of about 10 compared with the transition to the $3+$, $T=0$ ground state, but that the isotopic spin selection rule was responsible for a reduction in intensity by a factor of only two. The alpha-particle group corresponding to formation of the $T=1$ state was in fact symmetric about 90 deg at all the deuteron energies studied, but the ground-state group showed some forward peaking with 3.69-Mev deuterons.

For these reasons, tests of isotopic spin conservation in (d,α) and (α,d) reactions should be made between levels that are not both $0+$. Erskine and Browne studied the reaction $B^{10}(d,\alpha)Be^8$ (16.6 or 16.9 Mev, $T=1$ level).[29] The transition in this case was $3+(T=0)\rightarrow 2+(T=1)$, and it was found to be quite unhindered by the violation of the isotopic spin selection rule. However, the adjacent level which was used as an intensity standard may also be a $T=1$ level, and if this is so, the intensity comparison throws no light on the violation of the isotopic spin-selection rule.

For $J_f=1$, angular momentum and parity selection rules permit $L=0$, 2. The quadrupole moment of N^{14} (ground state) agrees with the value calculated for a ${}^3D_1$ $L-S$ state.[30] If its $j-j$ configuration $(p_{\frac{1}{2}}^2)_{J=1}$ wave function is expressed on an $L-S$ basis, it becomes[31]

$$(p_{\frac{1}{2}}^2)_{J=1}=(20/27)^{\frac{1}{2}}\,{}^3D_1-(1/27)^{\frac{1}{2}}\,{}^3S_1+(6/27)^{\frac{1}{2}}\,{}^1P_1.$$

The ${}^3D_1$ term is dominant, and from both $L-S$ and $j-j$ coupling, $L=2$ should be preferred to $L=0$ for the reaction $C^{12}(\alpha,d)N^{14}$ (ground state).

Attempts were made to determine the value of L or l_n and l_p by calculating (on the University of California IBM 704 computer) the angular distributions given by Butler's stripping theory[21] and by an equation given by El Nadi,[32] which derives from a plane-wave Born approximation two-nucleon stripping theory.

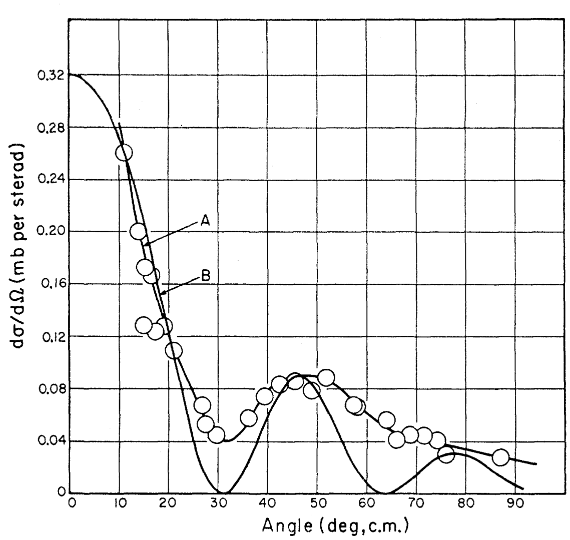

FIG. 6. Angular distribution of deuterons from formation of the 3.95-Mev level of N^{14}. Curve A presents the experimental results; Curve B, calculated results from the Butler equation using $l=2$, $r=5.5$ fermis.

[29] J. R. Erskine and C. P. Browne, Bull. Am. Phys. Soc. **5**, 230 (1960).
[30] E. Feenberg, *Shell Theory of the Nucleus* (Princeton University Press, Princeton, New Jersey, 1955).
[31] G. Racah, Physica **16**, 655 (1950).
[32] M. El Nadi, Proc. Phys. Soc. (London) **A70**, 62 (1957).

(The plane-wave approximation is unlikely to succeed well for an (α,d) reaction, since an interaction strong enough to break up an incident helium ion would surely cause considerable distortion of the outgoing deuteron wave.[21])

Figures 5 and 6 show the best fits to the angular distributions of the N^{14} ground state and 3.95-Mev state deuteron groups obtained with the Butler equation

$$\frac{d\sigma}{d\Omega}\propto\left|\frac{1}{q^2+\kappa^2}W[j_L(qr),\,h_L(\kappa r)]\right|^2,$$

where κ and q are defined as follows:

$$\kappa=[4.783\ m_cB+6.887\ m_cZ_1Z_2/r]^{\frac{1}{2}}\times10^{12},\ \mathrm{cm}^{-1},$$

where m_c is the reduced mass (in amu) of the captured particle in the final nucleus, B is the binding energy of the captured particle in the residual nucleus (in Mev), and Z_1 and Z_2 are the atomic numbers of the captured particle and the target nucleus.

$$q^2=k_i^2+\left(\frac{M_T}{M_F}k_f\right)^2-2M_Tk_ik_f\frac{\cos\theta}{M_F},$$

$$k_i=2.187\times10^{12}\left[\frac{M_\alpha M_T}{M_\alpha+M_T}E_\alpha\right]^{\frac{1}{2}},\quad \mathrm{cm}^{-1},$$

$$k_f=2.187\times10^{12}\left[\frac{M_dM_F}{M_d+M_F}(Q+E_\alpha)\right]^{\frac{1}{2}},\quad \mathrm{cm}^{-1},$$

where M_T and M_F are the masses of the target and final nuclei in (amu) and E_α is the incident helium ion energy (in Mev) in the center-of-mass system. Figures 5 and 6 show the calculated angular distributions for $L=2$ and $r=6.3$ fermis (N^{14} ground state) and $r=5.5$ fermis (3.95-Mev state). Unfortunately, equally good fits were obtained for $L=0$ and $r=6.4_5$ fermis (ground state) and $r=5.7$ fermis (3.95-Mev state).

Figures 7 and 8 show the best fits obtained for

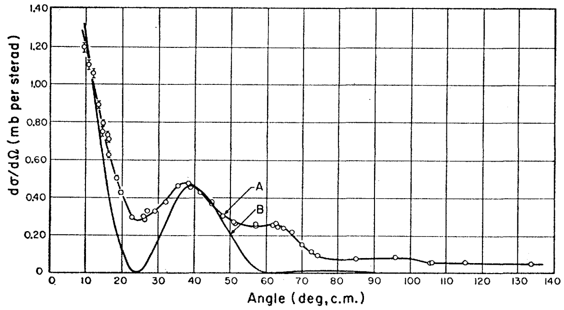

FIG. 7. Angular distribution of deuterons from formation of the ground state of N^{14}. Curve A presents the experimental results; Curve B, calculated results from the El Nadi equation using $l_n=l_p=1$, $r=4.57$ fermis.

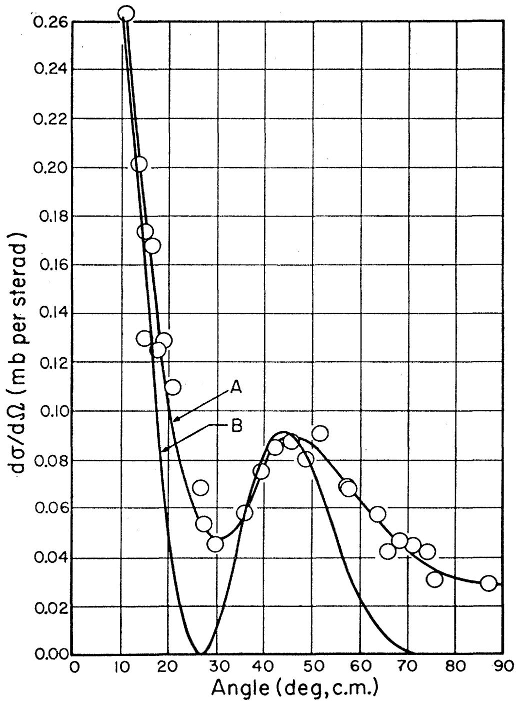

FIG. 8. Angular distribution of deuterons from formation of the 3.95-Mev level of N^{14}. Curve A presents the experimental results; Curve B, calculated results from the El Nadi equation using $l_n=l_p=1$, $r=4.22$ fermis.

$l_n=l_p=1$ with the El Nadi equation,

$$\frac{d\sigma}{d\Omega}\propto\exp\left(\frac{-G^2}{8\gamma^2}\right)\Bigg|\sum_{n=0}^{\infty}(n+\tfrac{1}{2})I_{n+\frac{1}{2}}(4\gamma^2r^2)$$
$$\times\sum_{L=|l_n-n|}^{l_n+n,2}\ \sum_{L'=|l_p-n|}^{l_p+n,2} j_L(gr/2)j_{L'}(gr/2)i^{L+L'}$$
$$\times C_{000}{}^{l_pnL'}C_{000}{}^{l_nnL}\sum_{m=\max(-l_p,\,-l_n,\,-n)}^{\min(l_n,l_p,n)}(-1)^m$$
$$\times C_{-mm0}{}^{l_nnL}C_{-mm0}{}^{l_pnL'}\Bigg|^2,\quad (1)$$

where r is the interaction radius, $G^2=(k_d-\frac{1}{2}k_\alpha)^2+2k_dk_\alpha\sin^2\theta/2$,

$$g^2=\left(k_\alpha-\frac{M_T}{M_F}k_d\right)^2+4\frac{M_T}{M_F}k_\alpha k_d\sin^2\left(\frac{\theta}{2}\right),$$

$$I_{n+\frac{1}{2}}(\rho)=i^{n+\frac{1}{2}}J_{n+\frac{1}{2}}(-i\rho),$$

and γ is the constant in the alpha-particle internal wave function $\exp(-\gamma^2\sum r_{ij}^2)$. A value of 0.279×10^{13} cm^{-1} was chosen for gamma to represent the measured rms radius of the alpha-particle charge density.[33]

Good fits to the experimental angular distributions

[33] R. Hofstadter, Revs. Modern Phys. **28**, 3, 214 (1956).

TABLE II. Values of l_n, l_p, and r for which Eq. (1) gave angular distributions in good agreement with experimental results.

N^{14} state	l_n	l_p	r (fermis)
Ground	0	0	5.08
	1	1	4.57
	2	0	4.65
	0	2	
	2	2	6.42
3.95 Mev	0	0	4.67
	1	1	4.22
	2	0	4.27
	0	2	

were obtained with all the sets of values of l_n, l_p, and r shown in Table II. Although the shell model requires $l_n=l_p=1$, the fits obtained with the other values shown in Table II were equally good. This unfortunate state of affairs makes it difficult to draw any conclusions about the spectroscopic states of N^{14} formed in the (α,d) reaction.

It has been suggested[27] that the N^{14} levels at 4.91 and 5.69 Mev have the configuration $s^4p^92s_{\frac{1}{2}}$, while the 5.10- and 5.82-Mev levels are $s^4p^9d_{\frac{5}{2}}$. Both these configurations would involve entry of the captured proton and neutron into different shell-model levels, or else a rather drastic rearrangement of the C^{12} core. Since at least two of these four levels were formed in high yields, it seems that the (α,d) reaction does not preferentially populate levels in which captured nucleons enter equivalent states.

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(He^4, Be^7) Reaction in Magnesium, Aluminum, Titanium, Cobalt, and Copper from Threshold to 42 Mev*

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Cross sections for the production of Be^7 in the He-ion bombardment of Mg, Al, Ti, Co, and Cu have been measured in the 30–42-Mev energy range. The excitation functions for these reactions are presented. A study of the bulk (0°–90°; 90°–180°) laboratory angular distributions by the catcher foil technique of the Be^7 nuclei emerging from 2.0- and 1.85-mg/cm² magnesium targets and an examination of the approximate range-energy curves for the Be^7 particles in aluminum and magnesium indicates that the reaction proceeds through a compound nucleus. The experimental excitation function for the $Al^{27}(He^4,Be^7)Na^{24}$ reaction is compared with calculations based on the nuclear evaporation model. The cross sections for the production of Na^{24} and Be^7 in the He-ion bombardment of aluminum are contrasted and the difference between the yields leads to an excitation function for the (He^4,He^3He^4) reaction.

INTRODUCTION AND THEORY

A STUDY of the production of Be^7 in the light elements with 30–42-Mev He-ions has indicated that a direct-interaction mechanism is responsible for the observed cross sections.[1] An apparent nonisotropic distribution in the center-of-mass system of the Be^7 particles which penetrate out of a thin target produced the above conclusion. A re-examination of the data given in reference one and observations of the bulk (0–90°; 90°–180°) angular distributions using the catcher foil method but thinner targets indicate that the apparent high forward yields observed are due to the fact that much too thick a target was used (3.1 mg/cm² Al) and the less energetic fragments which emerge into the backward hemisphere are unable to escape the target unless the (α,Be^7) event occurs near the rear surface. The comparatively large numbers of Be^7 decays observed in the target blur the angular distributions. An examination of the approximate range-energy curves for Be^7 particles and the kinetic

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[1] G. H. Bouchard, Jr., and A. W. Fairhall, Phys. Rev. 116, 160 (1959).