Stripping Effects in the Reactions $C^{12}(He^3,p)N^{14}$ and $C^{12}(He^3,d)N^{13}$ at 13.9 Mev*

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Angular distributions have been measured for the reactions $C^{12}(He^3,p)N^{14}$ and $C^{12}(He^3,d)N^{13}$ using the cyclotron 14-Mev He^3 beam. Assuming that the (He^3,p) reaction proceeds by the stripping of a deuteron in either its singlet or triplet state from the He^3 nucleus, reasonable fits to the angular distributions were obtained using a $[j_L(Qr_0)]^2$ dependence. For the transitions to the 1^+, $T=0$ ground and second excited states of N^{14}, $L=2$, $r_0=6.0$f, and $L=0$, $r_0=5.7$f, respectively. This is in accord with a predominant $^3D_1$ ground state and predominant $^3S_1$ second excited state configuration for N^{14}. For the transition to the 0^+, $T=1$ first excited state, $L=0$ and $r_0=5.7$f. Butler's stripping theory for the (He^3,d) reaction with $l_p=1$ and $r_0=5.8$f accounts reasonably well for the $C^{12}(He^3,d)N^{13}$ angular distribution.

INTRODUCTION

As the first experiment using the 14-Mev He^3 beam from the Purdue cyclotron, the angular distributions of three proton groups and one deuteron group produced from the bombardment of C^{12} have been measured.

The $C^{12}(He^3,p)N^{14}$ reaction has been studied previously for several bombarding energies between 1.30 and 6.05 Mev[1–3] using van de Graaff accelerators and at 21.0 Mev using a cyclotron.[4] Angular distributions of various proton groups have been measured by Bromley *et al.*[1] at 1.30 to 2.66 Mev (p_0, p_1, and p_2 groups),[5] Johnston *et al.*[2] at 2.0 to 5.0 Mev (p_0, p_1, and p_2 groups), Sweetman[3] at 6.05 Mev (p_0, p_1, p_2, $p_{3,4}$ groups) and Wegner and Hall[4] at 21.0 Mev. For energies between 1.30 and 5.0 Mev, the angular distributions show both compound-nucleus and direct-interaction effects. The 4.5-Mev data[2] for the p_0 and p_2 angular distributions have been analyzed with moderate sucess by El Nadi and El Krishin[6] in terms of a two-nucleon forward stripping process and the heavy-particle stripping of a proton from the C^{12} nucleus. At 6.05 Mev, the angular distributions are peaked at 0° and the direct-interaction character is better represented. In a preliminary measurement, Wegner and Hall[4] have reported that at 21.0 Mev, the direct interaction character is well represented. The gap in these measurements for energies between 6.05 and 21.0 Mev is now partially filled in by the present measurements at 13.9 Mev.

Because of the negative ground-state Q value of 3.553 Mev for the $C^{12}(He^3,d)N^{13}$ reaction,[7] this reaction has not been studied for the bombarding energies available from van de Graaff accelerators. Wegner and Hall[4] have measured the angular distributions of the d_0, d_1, and $d_{2,3}$ groups for energies of 21.0 and 24.0 Mev. The angular distributions are peaked in the forward direction and exhibit the diffraction-type patterns characteristic of direct-interaction processes.

The Purdue data at 13.9 Mev for the angular distribution of the d_0 group from the reaction $C^{12}(He^3,d)N^{13}$ adds another measurement at an energy substantially lower than the previous energies which can be used to study the trends of the angular distributions as a function of bombarding energy.

The theory of the (He^3,d) stripping reaction which has been treated by Butler[8] with the same rigor as the (d,n) and (d,p) stripping reactions has been applied to the $C^{12}(He^3,d_0)N^{13}$ data. The theoretical curve is based on Eq. (12.4) of reference 8.

The (He^3,p) reaction has as yet received little theoretical attention. El Nadi and El Krishin[6] and, recently, Newns,[9] have developed quite complicated, two-nucleon stripping theories for (He^3,p) reactions. The expressions for the angular distributions are difficult to evaluate and do not lend themselves to simple analyses. However, assuming that the reaction proceeds by the stripping of a deuteron with a definite spin, isotopic spin, and parity, they can be approximated by,[9,10]

$$\sigma(\phi)\sim\sum_L [A(L)j_L(Qr_0)]^2. \qquad (1)$$

$L\hbar$ is the orbital angular momentum of the captured

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[1] D. A. Bromley, E. Almquist, H. E. Gove, A. E. Litherland, E. B. Paul, and A. J. Ferguson, Phys. Rev. **105**, 957 (1957).

[2] R. L. Johnson, H. D. Holmgren, E. A. Wolicki, and E. G. Illsley, Phys. Rev. **109**, 884 (1958).

[3] D. R. Sweetman, Bull. Am. Phys. Soc. **3**, 186 (1958), and private communication.

[4] H. E. Wegner and W. S. Hall, Bull. Am. Phys. Soc. **3**, 338 (1958), and private communication. See also D. A. Bromley and E. Almquist, Chalk River Laboratory Report, Chalk River, Ontario (unpublished).

[5] The notation p_i group means that proton group which leaves the residual nucleus in its ith excited state. $i=0$ denotes the ground state.

[6] M. El Nadi and M. El Krishin, Proc. Phys. Soc. (London) **73**, 705 (1959).

[7] F. Ajzenberg-Selove and T. Lauritsen, Nuclear Phys. **11**, 1 (1959).

[8] S. T. Butler and O. H. Hittmair, *Nuclear Stripping Reactions* (John Wiley & Sons, Inc., New York, 1957).

[9] H. C. Newns, University of Liverpool, Liverpool, England (private communication).

[10] S. Hinds and R. Middleton, Proc. Phys. Soc. (London) **74**, 196 (1959).

deuteron and is determined from the relations

$$\mathbf{J}_f = \mathbf{J}_i + \mathbf{S}_D + \mathbf{L}, \tag{2}$$

$$|\mathbf{J}_f - \mathbf{J}_i - \mathbf{S}_D|_{\min} \leqslant L \leqslant J_f + J_i + S_D. \tag{3}$$

J_i and J_f are the spins of the initial and final nuclear states, S_D is the spin of the captured deuteron and can be 0 or 1, and L is odd only if there is a parity change between the initial and final states. $A(L)$ is a constant which depends only on the nuclear properties of the states formed, r_0 is the interaction radius, and $\mathbf{Q} = \mathbf{k}_{\mathrm{He}^3} - (m_i/m_f)\mathbf{k}_p$, where $\mathbf{k}_{\mathrm{He}^3}$ and $\mathbf{k}_p$ are the wave vectors of the He^3 particle and proton in the center-of-mass system and m_i and m_f are the masses of the target and residual nuclei. Approximate expressions of this form have been used with good success by Hinds and Middleton[10–12] in the analysis of (He^3,p) angular distributions at lower He^3-particle energies. Where two L values are allowed, they have determined the ratio $A(L_1)/A(L_2)$ from the best fits to the experimental data. The same type of analysis has been applied to the (He^3,p) data to be presented here.

EXPERIMENTAL METHODS AND TECHNIQUES

Beam and Energy Spread

The external 14-Mev He^3 beam was focused by two pairs of magnetic quadrupole lenses and was analyzed magnetically by a symmetrical wedge magnet. The analyzing magnet was calibrated using the 5.3054 ±0.0010-Mev[13] alpha particles from Po^{210}. The rms energy deviation from the nominal value due to finite geometry and imperfect focusing was 24 kev.

The beam current as measured in a Faraday cup was integrated by the method of Higinbotham and Rankowitz[14] to obtain the total incident charge. To check the integrator and account for changes in target thickness and target orientation due to bombardment by the beam and carbon accumulation on the target, two CsI(Tl) scintillation spectrometers utilizing Dumont 6365 phototubes were placed at equal angles (~17.5°) with respect to the incident beam.

He^3 Recirculating and Recovery System

The Purdue cyclotron is a fixed-frequency machine operating at about 12.3 Mc/sec. The properly shimmed magnetic field required to accelerate 19-Mev alpha particles and 9.5-Mev deuterons is about 16 000 gauss. In order to accelerate He^3 particles, it was necessary to completely reshim the magnet at 75% of the normal field. This was done by very accurately mapping the magnet field using a nuclear-resonance fluxmeter. These He^3 shims can be exchanged readily for the full-field shims used for the acceleration of He^4 and H^2.

Because of the present cost of He^3 gas it is necessary to recirculate the unused gas from the ion source. A schematic diagram of the He^3 recirculating system is shown in Fig. 1. The heavy line and arrows indicate one of two gas paths for supplying the gas to the ion source. With the exception of the impurity traps, the system is similar to that used by Wegner and Hall[15] in the variable-energy machine at the Los Alamos Scientific Laboratory. The Los Alamos system uses an activated charcoal trap while the Purdue system freezes out the impurities by pumping the unused gas into a Monel cylinder surrounded by liquid helium. The operation of the system is as follows: as shown schematically in Fig. 1, the gas is in trap *T* II and the trap *T* I is empty. The gas flow to the ion source is regulated remotely by the needle valve *N* and the unused gas from the ion source is pumped by a Cenco Hypervac 20 pump (with an external oil system for lubricating the shaft) from the cyclotron back into trap *T* II, where the impurities are frozen out. At the end of the day's run, valve 7 is closed and as much as possible of the He^3 gas remaining in the cyclotron and associated lines is recovered. The gas from the trap being used is then

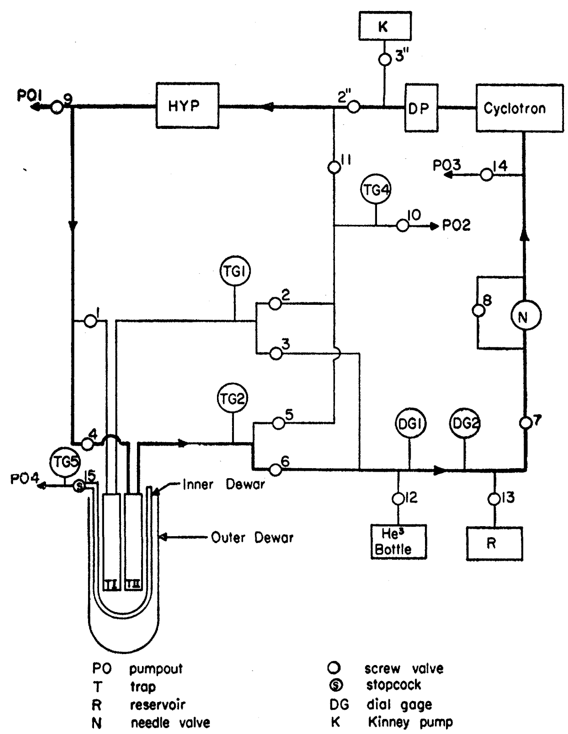

FIG. 1. Schematic drawing of the He^3 recirculating and recovery system. The heavy line and arrows indicate one of two possible gas paths for the ion source.

[11] S. Hinds and R. Middleton, Proc. Phys. Soc. (London) **74**, 762 (1959).

[12] S. Hinds and R. Middleton, Proc. Phys. Soc. (London) **74**, 779 (1959).

[13] F. A. White, F. M. Rourke, J. C. Sheffield, R. P. Schuman, and J. R. Huizenga, Phys. Rev. **109**, 437 (1958).

[14] W. A. Higinbotham and S. Rankowitz, Rev. Sci. Instr. **22**, 688 (1951).

[15] H. E. Wegner and W. S. Hall, Rev. Sci. Instr. **29**, 1100 (1958).

transferred over to the evacuated trap and sealed off. Both traps are then brought to room temperature and the impurities are pumped out of the trap that was used for the day's run. For the next run, the same procedure is followed using the trap which now contains the He^3 gas.

No trouble was encountered in the operation of the recirculating system. He^3 particles were accelerated for periods up to 16 hours without having to pump the impurities out of the traps. It is estimated that the loss of gas is of the order of 1 cm^3 per hour at STP.

Reaction Chamber

The reaction chamber used was the one used in this laboratory for the study of alpha-particle scattering.[16] A $6\frac{3}{4}$-inch collimator with $\frac{1}{8}$-inch diameter apertures defines the incident beam to within $\pm 1.06°$ of the nominal beam direction. The chamber lid was mounted on $\frac{3}{32}$-inch diameter steel ball bearings and an *O*-ring seal lubricated with Dow-Corning 200 fluid so that it could be rotated under vacuum. The geometry and mechanics of the chamber permit the observation at laboratory reaction angles between 11° and 169°. The solid angle subtended by the $\frac{5}{32}$-inch diameter defining aperture used was 0.785×10^{-4} steradian. The maximum rms deviation from the nominal laboratory reaction angle which is defined as the angle between the axis of the collimator and the normal to the defining aperture was 0.9°. To reduce the accumulation of carbon deposits on the target, a refrigerator was installed around the throat of the diffusion pump used to evacuate the chamber.

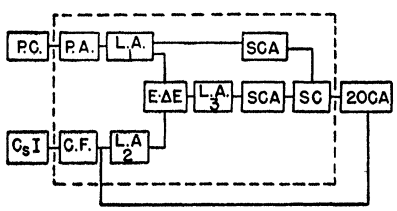

FIG. 2. Block diagram of the electronics used in conjunction with the proportional counter-CsI scintillation spectrometer counter telescope. The gating circuit shown within the dashed lines is used only when deuterons are counted. P.C.—proportional counter; P.A.—Atomic 205-B preamplifier; L.A.1, L.A.2—Atomic 219 linear amplifiers with modified output circuits; CsI— scintillation spectrometer; C.F.—White cathode follower preamplifier; $E\cdot\Delta E$—Los Alamos multiplying circuit; L.A.3—Atomic 204-B linear amplifier; SCA—single-channel analyzer; SC—slow coincidence circuit; 20CA—Atomic 520 twenty-channel analyzer.

Target

Since polyethylene foils were found to deteriorate under prolonged bombardment, a film of polystyrene, $[(CH)(C_6H_5)(CH_2)]_n$, of thickness about 1.5 mg/cm^2 was used for the C^{12} target. It was prepared by dissolving

[16] O. H. Gailar, E. Bleuler, and D. J. Tendam, Phys. Rev. 112, 1989 (1958).

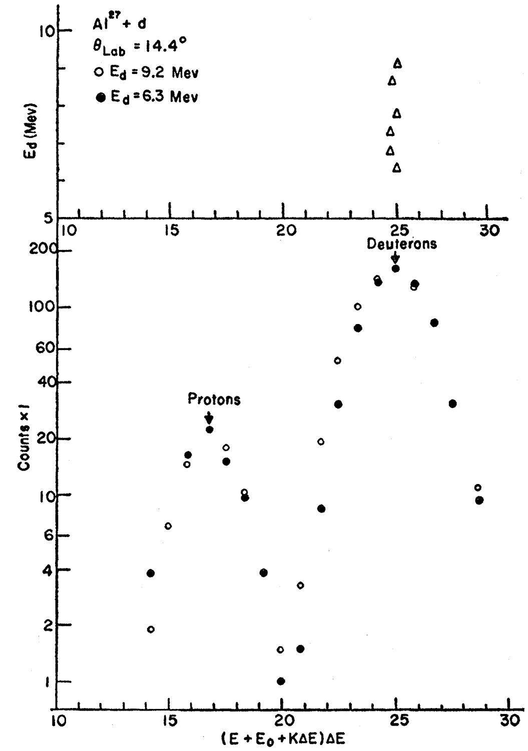

FIG. 3. Multiplied spectra obtained when Al^{27} is bombarded with 9.5-Mev deuterons. The upper plot illustrates the constancy of the mean multiplied pulse-height for deuterons as the energy is changed.

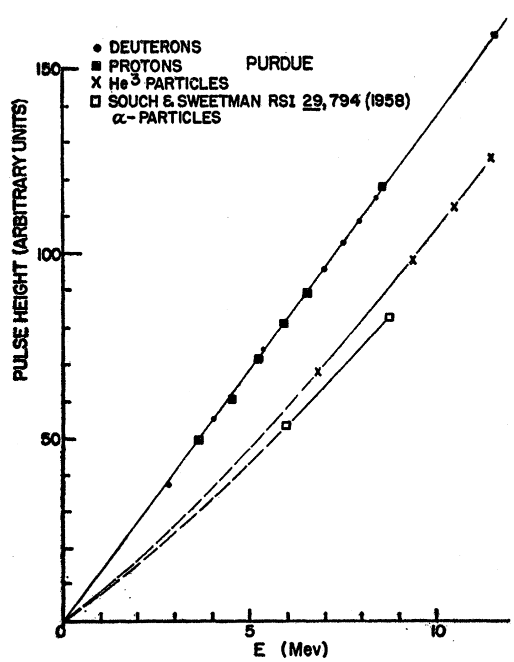

FIG. 4. Response of CsI(Tl) to deuterons, protons, He^3, and alpha particles. The relative proton-alpha-particle pulse-height data of Souch and Sweetman have been normalized to the Purdue data for protons, deuterons, and He^3 particles.

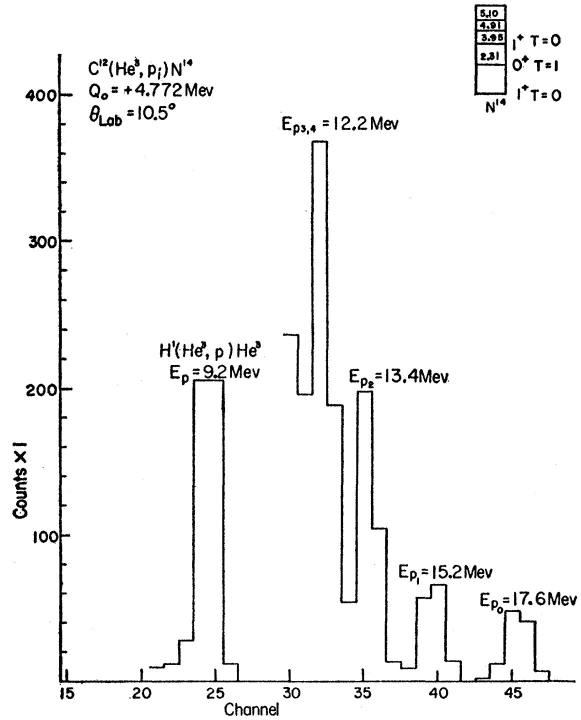

FIG. 5. Typical proton histogram for $C^{12}(He^3,p)N^{14}$.

commercial 0.001-inch polystyrene sheet[17] in benzene and allowing the benzene to evaporate after the mixture is placed on a water surface. The number of C^{12} nuclei per cm^2 as seen by the incident beam was determined by comparing the cross section for the elastic scattering of 19-Mev alpha particles from a known thickness of polyethylene, $[(CH_2)(CH_2)]_n$, to the cross section for the elastic scattering of 19-Mev alpha particles from the polystyrene target. To insure that the mean He^3-particle energy was the same for all the differential cross sections measured, the target was always oriented at 45° with respect to the incident beam. The target was then 0.44 Mev thick for 14-Mev He^3 particles.

Particle Detection and Discrimination

The detection head was a counter telescope consisting of a gas[18] proportional (ΔE) counter and a CsI(Tl) (E) scintillation spectrometer having a resolution of better than 4% for 9-Mev deuterons and protons. The Q values for all competing reactions and the long range of the protons as compared to deuterons, tritons, He^3 particles, and alpha particles of comparable energy, allow one to distinguish the protons simply by absorbing out, or sufficiently degrading the energy of, all shorter range reaction products. Making use of the fact that the product EdE/dx is approximately proportional to the mass of the ionizing particle, the deuterons from the reaction $C^{12}(He^3,d)N^{13}$ were identified by multiplying the ΔE pulses from the proportional counter with the E pulses from the scintillation counter.

In the vicinity of the reaction chamber, especially near the collimator, there is an intense gamma-ray background. This gamma-ray background was completely eliminated from the proton and deuteron groups studied by using sufficiently thin CsI crystals. This method avoids the requirement of a fast coincidence between the proportional counter and CsI counter pulses for the proper identification of the particles in the groups studied.

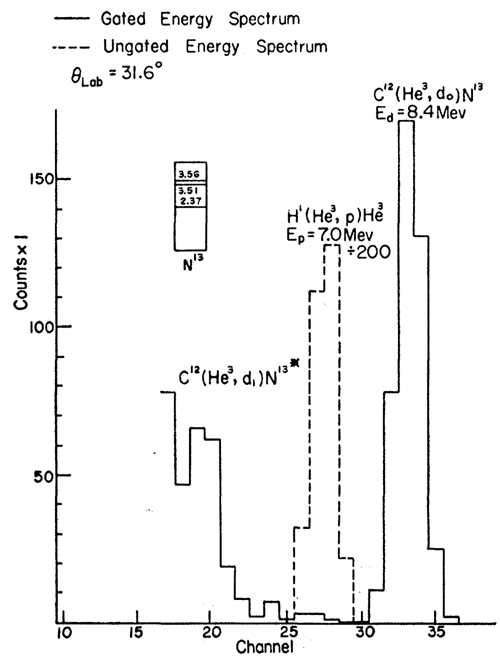

FIG. 6. Typical gated and ungated deuteron histogram for $C^{12}(He^3,d)N^{13}$. Only the d_0 group was resolved because of the energetics of the reaction. The very intense proton peak shown in dashed lines, reduced by a factor of 200, is due to knock-on protons from the hydrogenic content of the target.

Electronics

A block diagram of the electronics used in conjunction with the E and ΔE counters is shown in Fig. 2. The deuteron gating circuitry is shown within the dashed lines.

The multiplying circuit is a duplicate of the one originated at the Los Alamos Scientific Laboratory.[19,20] The circuit actually multiplies $[E+E_0+k\Delta E]\Delta E$, where E_0 and k are constants ($0\leqslant k\leqslant 1$). This product was shown by the authors[20] to be more constant than $\Delta E\times E$ as a function of energy when the energies are low ($\leqslant 15$ Mev). The quality of the deuteron-proton

[17] Kindly supplied by the Dow Chemical Company, Midland Michigan.
[18] Commercial P–10 gas (90% argon, 10% methane) obtained from the Matheson Co. was used.
[19] W. L. Briscoe, Rev. Sci. Instr. **29**, 401 (1958).
[20] R. H. Stokes, J. A. Northrop, and K. Boyer, Rev. Sci. Instr. **29**, 61 (1958).

discrimination is illustrated in Fig. 3. Conventional linear amplifiers, pre-amplifiers and single-channel analyzers and an Atomic Instrument Model 520 twenty-channel pulse-height analyzer were used in conjunction with the multiplying circuit. The completeness of the deuteron-proton separation was enhanced by requiring a coincidence from the proper multiplied and the proportional (ΔE) counter pulses. The coincidence circuit was of the Garwin type and had a resolving time of about 1.5 μsec.

When the protons were counted, the gating circuitry was completely removed and the gas was removed from the proportional counter.

Analysis of the Data

The pulse-height data recorded on the twenty-channel pulse-height analyzer were plotted in the form of

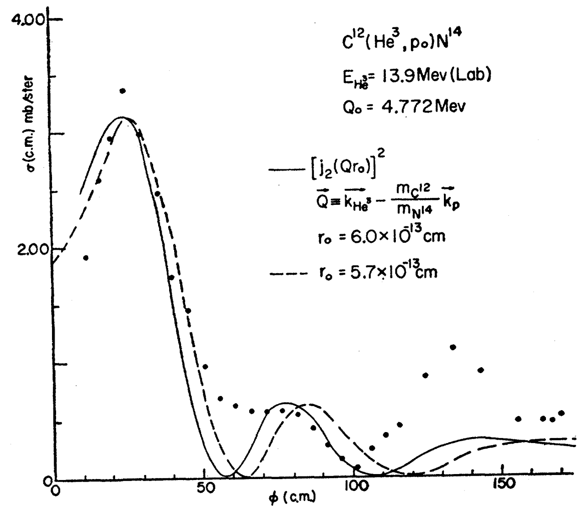

FIG. 7. Theoretical fits to the angular distribution of the p_0 group from the reaction $C^{12}(He^3,p)N^{14}$.

histograms. Since the pulse height from the CsI(Tl) scintillation spectrometer is proportional to the energy of the ionizing particle and the response is linear for protons and deuterons[21,22] (Fig. 4), the protons and deuterons were identified by comparing the mean pulse height (channel) for a given group with the mean pulse heights for other, known groups. The mean energy in the target was calculated using the incident He^3-particle energy obtained from the calibration of the analyzing magnet and the Q values for the reactions taken from Ajzenberg-Selove and Lauritsen.[7] Energy losses in the target, counter vacuum seals, and aluminum absorbers were calculated from the data of Whaling.[23] A typical proton histogram for the $C^{12}(He^3,p_i)N^{14}$ reaction is

[21] S. Bashkin, R. R. Carlson, R. A. Douglas, and J. A. Jacobs, Phys. Rev. **109**, 434 (1958).
[22] R. A. Peck and H. P. Eubank, Rev. Sci. Instr. **30**, 703 (1959).
[23] W. Whaling, *Handbuch der Physik*, edited by S. Flügge (Springer-Verlag, Berlin, 1958). Vol. 34, p. 193.

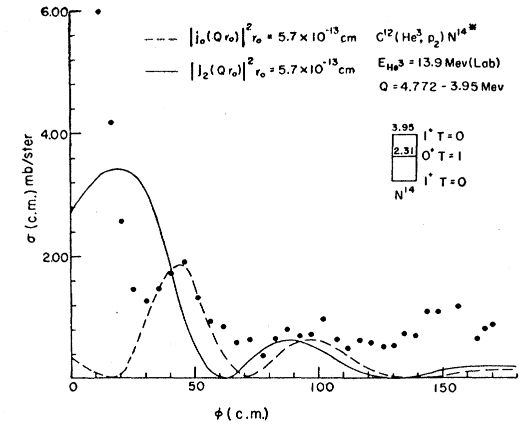

FIG. 8. Theoretical fits to the angular distribution of the p_2 group from the reaction $C^{12}(He^3,p)N^{14}$.

shown in Fig. 5. The p_0 and p_1 groups were clearly resolved. Some difficulty was encountered in unfolding the p_2 group from a more intense lower energy proton background. In Fig. 6 a typical gated and ungated energy spectrum for the $C^{12}(He^3,d)N^{13}$ reaction is shown. Because of the energetics of the reaction, only the d_0 group was clearly resolved. The effectiveness of the gating circuitry is illustrated by the disappearance of the very intense "knock-on" proton group which comes from the hydrogenic content of the target.

RESULTS AND DISCUSSION

$C^{12}(He^3,p_i)N^{14}$

The angular distributions of the p_0, p_1, and p_2 groups from the reaction $C^{12}(He^3,p_i)N^{14}$ are shown in Figs 7, 8, and 9. The mean He^3-particle energy was 13.9 Mev. For the region of angles less than 90° the counting

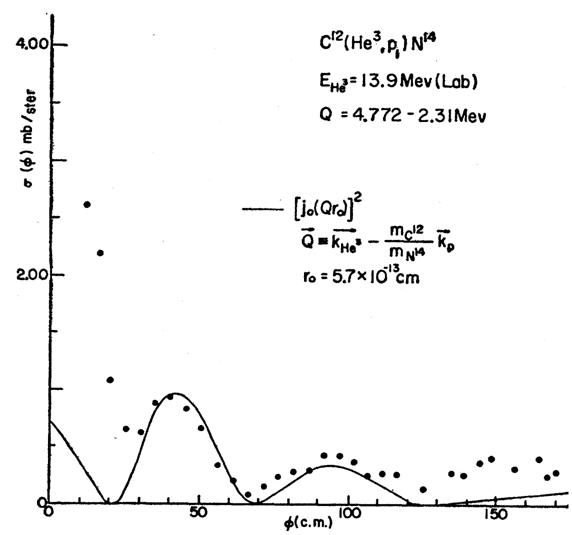

FIG. 9. Theoretical fit to the angular distribution of the p_1 group from the reaction $C^{12}(He^3,p)N^{14}$.

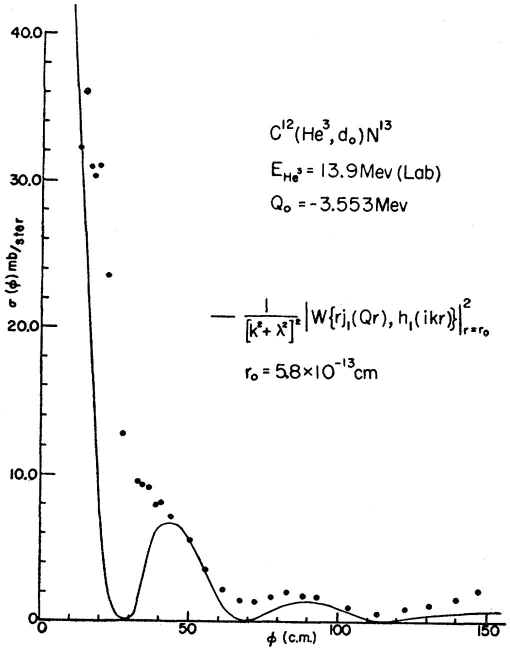

FIG. 10. Theoretical fit to the angular distribution of the d_0 group from the reaction $C^{12}(He^3,d)N^{13}$.

statistics are better than 6%. Thereafter, they are no better than 10%.

For the transitions which lead to the 1^+, $T=0$, ground and second excited states of N^{14}, the selection rule [Eq. (3)] for the reaction which strips a deuteron in its triplet state from the He^3 nucleus allows $L=0$ and $L=2$. A predominant $L=2$ transition for the $C^{12}(He^3,p_0)N^{14}$ reaction is indicated by the good fit obtained for the p_0 angular distribution using only $[j_2(Qr_0)]^2$ with $r_0=6.0$f (Fig. 7). A better fit (Fig. 7) to the forward peak is obtained using $r_0=5.7$f but the over-all agreement is reduced. The predominant $L=2$ deuteron capture supports the findings of Visscher and Ferrell[24] for a nearly pure $^3D_1$ configuration for the N^{14} ground state. The p_2 angular distribution is fitted best by $[j_0(Qr_0)]^2$ with $r_0=5.7$f even though the theoretical curve grossly underestimates the experimental intensity in the forward angles (Fig. 8). $[j_2(Qr_0)]^2$ with $r_0=5.7$f is seen to be inconsistent with the experimental curve. Visscher and Ferrell[24] find, in agreement with our results, a predominant $^3S_1$ configuration for the second excited state of N^{14}.

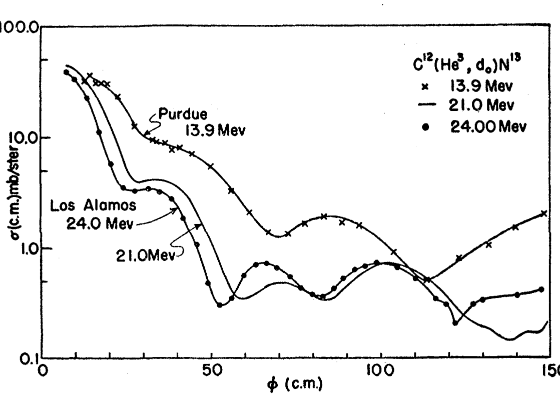

FIG. 11. Comparison of the Purdue $C^{12}(He^3,d)N^{13}$ data at 13.9 Mev with that of H. E. Wegner and W. S. Hall of the Los Alamos Scientific Laboratory at 21.0 and 24.0 Mev.

Only $L=0$ capture for deuterons in the singlet state is allowed by the selection rule for the $C^{12}(He^3,p_1)N^{14}$ reaction. A good fit (Fig. 9) to the p_1 angular distribution is obtained for the region of angles greater than ~25° using $[j_0(Qr_0)]^2$ and an interaction radius of 5.7f. But, as for the p_2 angular distribution, $[j_0(Qr_0)]^2$ grossly underestimates the experimental intensity in the forward angles. In both cases, the forward peak can be fitted better if a smaller interaction radius is used but the over-all agreement is vastly reduced. A similar effect, using the same type of analysis, was observed for the $C^{12}(\alpha,p)N^{15}$ reaction at 41.5 Mev.[25]

The $C^{12}(He^3,p)N^{14}$ angular distributions have shown a remarkable likeness to the predictions of a crude stripping theory, thus lending credence to the supposition that a deuteron is stripped from the He^3 nucleus. It should be pointed out that the transitions to the 1^+, $T=0$ states of N^{14} (p_0,p_2) by capture of a deuteron in its singlet state are forbidden as is the transition to the 0^+, $T=1$ first excited state of N^{14} by capture of a deuteron in its triplet state. The angular distributions and total cross sections for the three transitions can then, when analyzed in the light of a more realistic theory, yield information about the strengths of the deuteron singlet and triplet states in the He^3 nucleus. In view of the possibility of such a calculation, the differential cross sections were integrated over solid angle with the results (accurate to 5%) $\sigma_{total}(p_1) = 0.54\sigma_{total}(p_0) = 0.46\sigma_{total}(p_2)$.

TABLE I. Energy dependence of the momentum transfers Q (in 10^{13}cm^{-1}) for the first three minima of the differential cross section of the reaction $C^{12}(He^3,d_0)N^{13}$.

E_{He^3}	13.9 Mev (ϕ_{min})	Q	21.0 Mev (ϕ_{min})	Q	24.0 Mev (ϕ_{min})	Q
1	(37.0°)	0.70	(28.8°)	0.72	(25.6°)	0.70
2	(70.0°)	1.12	(58.4°)	1.21	(53.8°)	1.21
3	(115.0°)	1.59	(85.0°)	1.63	(81.3°)	1.69

$C^{12}(He^3,d_0)N^{13}$

The angular distribution of the d_0 group from the reaction $C^{12}(He^3,d)N^{13}$ is shown in Fig. 10. The mean He^3-particle energy and the counting statistics were the same as for the $C^{12}(He^3,p_i)N^{14}$ experiments.

The angular distribution is fitted reasonably well by Butler's theory[8] for the stripping of a proton from the He^3 particle. An interaction radius of 5.8f was used.

[24] W. M. Visscher and R. A. Ferrell, Phys. Rev. **107**, 781 (1957).

[25] R. Sherr and M. Rickey, Bull. Am. Phys. Soc. **2**, 29 (1957).

The $l_p=1$ assignment is in agreement with the assumed spin and parity of the ground state of N^{13}.[7] The zeros of the theoretical curve are in good agreement with the minima of the experimental curve and the amplitude of the strong forward peak is accounted for reasonably well.

In Fig. 11 these data are compared with the data of Wegner and Hall[4] at 21.0 and 24.0 Mev. As seen, the angular distributions do not change radically in this energy interval and the minima show a systematic shift toward smaller angles as the bombarding energy is increased. If, as is true for most simple direct-interaction theories, the angular dependence is contained in some function of Qr_0, then, assuming that r_0 is constant, the value of Q for a given minimum should be independent of energy. Inspection of Table I shows that the values of Q for a given minimum are nearly independent of energy in this energy range. This leads one to believe that the reaction does indeed proceed by a simple direct process and that the angular distributions will be explained in more detail by a more sophisticated expression.

SUMMARY

Using a crude theory for the $C^{12}(He^3,p_i)N^{14}$ reaction, the angular distributions were fitted by simple $[j_L(Qr_0)]^2$ functions. In fitting these data an effort was made to correlate the minima in the experimental angular distributions with the zeros of $j_L(Qr_0)$ and to keep the interaction radius reasonably constant. This was done with good success using interaction radii of 6.0, 5.7, and 5.7 fermis and $L=2$, 0, and 0 for the p_0, p_1, and p_2 angular distributions, respectively. The theoretical curves, however, grossly underestimate the experimental intensity in the forward angles of the p_1 and p_2 angular distributions. If more freedom is allowed for the value of the interaction radius, the forward part of these experimental curves can be accounted for, but the over-all agreement is vastly reduced.

The $C^{12}(He^3,d_0)N^{13}$ data were compared with Butler's theory[8] for the stripping of a proton from the He^3 nucleus. Good agreement between the zeros of the theoretical curve and the minima of the experimental curve was obtained, though the latter were not always well defined, and the shape of the experimental curve was accounted for reasonably well.

It is expected that just as for (d,p) and (d,n) stripping reactions, more detailed analyses, especially the distorted wave calculations, will remedy some of the deficiencies of the simple stripping theories used here.

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Angular Distributions for $C^{12}(\alpha,p)N^{15}$ at 16.1–19.0 Mev and $F^{19}(\alpha,p)Ne^{22}$ at 18.9 Mev*

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Angular distributions have been measured for the reactions $C^{12}(\alpha,p)N^{15}$ and $F^{19}(\alpha,p)Ne^{22}$ using the cyclotron 19-Mev alpha-particle beam. The $C^{12}(\alpha,p_0)N^{15}$ data at 18.0, 17.1, and 16.1 Mev differ markedly from the 19.0-, 18.7-, and 18.3-Mev data; the latter three are very similar to each other. The differential excitation function at 31.8° (lab) shows a resonance at 17.5 Mev with a width at half-maximum of $\sim$2 Mev. Steep backward peaking is observed in the 16.1-Mev data. Some of the features of the 17.1- and 18.0-Mev data can be represented by Butler's formula for (α,p) reactions using $l=1$ and $r_0=5.9$ and 5.5f, respectively. For the $F^{19}(\alpha,p)Ne^{22}$ data the cross sections for the transition to the ground state of Ne^{22} are factors of 10 to 20 less than the cross sections for the transition to the first excited state of Ne^{22}. This inhibition, together with the $F^{19}(n,d)O^{18}$ data, may be explained by assuming that the two last neutrons of F^{19} are not disturbed in the direct interactions and that they are in a $(d_{5/2}{}^2)_0$ configuration in Ne^{22}, in a $(d_{5/2}{}^2)_2$ or $(s_{1/2}{}^2)_0$ configuration in F^{19}. Using $r_0=5.1$f, Butler's formula accounts reasonably well for the forward peak and the location of the minima of all three angular distributions for the region of angles less than 90°. The angular distributions are all peaked in the backward angles.

INTRODUCTION

THE proton angular distributions to be reported here are the first of a series of measurements using low and medium Z target nuclei and the 19-Mev alpha-particle beam from the Purdue cyclotron in which an endeavor is being made to determine the magnitude

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