Angular Distribution of Protons in the $N^{14}(dp)N^{15}$ Reaction*

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The Yale cyclotron was used to investigate the angular distributions of protons emitted in the reaction $N^{14}(dp)N^{15}$ employing bombarding energies between 1.5 Mev and 3.0 Mev. Both the ground state and first excited state protons were studied. Over the energy range used, the protons emitted in the formation of the ground state are found to have a slightly higher yield in the forward direction while those emitted in the formation of the first excited state are essentially spherically symmetric. Neither distribution shows marked variation with energy.

INTRODUCTION

RECENTLY increasing attention has been given to the angular distribution of particles emitted in nuclear disintegrations in order to gain additional information on the nature of nuclear energy levels and the mechanisms governing nuclear disintegrations. It was felt that the comparison of the angular distributions of particles emitted in the formation of two states of the same residual nucleus might furnish helpful information regarding spin differences and selection rules. The high degree of excitation of the first excited state of N^{15} (5.42 Mev) suggested that the reaction $N^{14}(dp)N^{15}$ might be particularly interesting. The fact that the low yield ground state protons have a longer range than possible contaminants, and that the short range excited state protons have a much higher yield, makes this reaction particularly suitable for such studies. Previous work on the angular distribution of two groups arising from one reaction has been done by Heydenburg and Inglis[1] using the reaction $O^{16}(dp)O^{17}$. Guggenheimer, Heitler, and Powell[2] obtained some information on the angular distribution of the nitrogen proton groups in connection with their work on scattering of 6.5-Mev deuterons by nitrogen, but the distributions of the proton groups was not given. No attempt has been made to analyze the data for possible explanation for the differences in the distribution.

EQUIPMENT

In order to make the proton pulses from the proportional counter as large as possible with respect to the background they must be counted near the end of their range. Since this range is variable with angle, a selsyn foil changer operated from the cyclotron control panel is used to insert aluminum foils between the bombardment chamber and the detecting counter so that the residual range in the counter is the same at all angles. Equivalent air ranges up to 208 cm in 1-cm steps may be obtained with the one now in use.

A diagram of the experimental equipment is shown in Fig. 1. The gas chamber is isolated from the cyclotron by an aluminum foil of known stopping power. In order to obtain lower energies, additional foils were ininserted in the cyclotron beam. To permit alignment of the tube with the beam, a sylphon was used to connect the tube to the cyclotron mounting flange. Proper adjustment of the sylphon was obtained by waxing a fluorescent plate on the end of the tube and adjusting the sylphon for proper alignment of the slits in the beam tube for a given current through the beam deflecting magnet.

Two chambers were used, differing essentially only in the height of the proton port which extends from 0° to 145°. The first chamber for the long range group had a $\frac{5}{8}$-in. slot over which it was found necessary to wax a foil of 45-cm air equivalent. The bowing of thinner foils when the cylindrical chamber was evacuated caused the formation of ridges in the foil. For use with the excited group, the foil thickness had to be reduced to 5-cm air equivalence; therefore, it was necessary to construct a new chamber having a $\frac{1}{4}$-in. slot. The proton slit system gives a maximum half-width of slightly less than 6°; however, 60 percent of the measured yield comes from a region of the target gas for which the counter opening subtends an angle of only 3.5°.

The gas chamber is insulated from the beam tube, and the beam measured is that collected by the chamber. The presence of gas in the chamber and the fact that the isolating foil is at ground potential, prevents the use of the usual current integrator, therefore a monitor counter was used. It was found that with the excited group chamber the beam which passed through the chamber and out into the air caused considerable ionization and erratic galvanometer readings; thus, the monitor counter was relied upon entirely for beam integration.

A screw lock at the center of the spectrometer table engages a center pin on the bottom of the gas chamber. The proton slit system, foil changer, and counter are all mounted on the selsyn foil changer table. An arm under the center of the slit system and pivoted at the center of the table is used to set this equipment at the

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[1] N. P. Heydenburg and D. R. Inglis, Phys. Rev. 73, 230 (1948).
[2] Guggenheimer, Heitler, and Powell, Proc. Roy. Soc. (London) 190, 196 (1947).

desired angle by using the degree graduations on the spectrometer table. The over-all accuracy of placement is within one degree.

The counters and preamplifiers were those described by Martin.[3] The video circuits were reported by Benson.[4]

PROCEDURE

For work on the ground state protons, the bias on the counting circuits was kept as low as possible consistent with low background. Under such conditions it was found that the yield as a function of the absorption is essentially flat over a spread of 20 cm and thus, that the yield is practically independent of the absorption. For work on the first excited state it was necessary to discriminate against the long range ground state protons and to be sure that no yield from possible contaminants such as oxygen (commercial nitrogen was used) be detected. Thus, it was necessary to increase the bias level until no counts were recorded from the less ionizing long range protons and so that it was clearly evident at what absorption the shorter range contaminant protons were detected. It was found that under such conditions the yield of the short range protons was constant over an absorption of at least 6 cm. The gas chamber was filled to a pressure of 10 cm of nitrogen.

At any given bombardment energy, the particular group in question was first located with the movable counter (usually set at 90°), and the bias was adjusted to obtain the desired shape of the yield *vs.* range curve. Spot checks were then made at other angles to see that agreement existed between the observed range and the precalculated ranges using the average Q-values for $N^{14}(dp)N^{15}$ as reported by Holloway and Moore[5] and Davison and Pollard.[6] In this manner the absorption to be used at every angle was chosen prior to starting a given run. The data were recorded in terms of the number of counts received in the movable counter per standard number of counts in the monitor. Since the yield near 90° was always a minimum, the standard number of monitor counts for any given run was chosen to give a statistical error of less than 5 percent at 90°. However, due to the increased background, this statistical error for the 1.5-Mev and 2.08-Mev long range group was approximately 7 percent. Readings were made at every 15° between 15° and 135°. Since the 90° yield was chosen as standard, the 90° yield was checked frequently.

The background was subtracted from the observed yield at each angle, and the corrected yield was multiplied by the sine of the angle to account for the varying target thickness as a function of angle. A correction of 4 percent was made to the data at 15° for the increased solid angle subtended by the counter caused by the fact that part of the target is closer to the counter.

[3] A. B. Martin, Phys. Rev. **72**, 378 (1947).
[4] B. B. Benson, Rev. Sci. Inst. **17**, 533 (1946).
[5] M. G. Holloway and B. L. Moore, Phys. Rev. **58**, 847 (1940).
[6] P. W. Davison and E. C. Pollard, Phys. Rev. **72**, 162 (1947).

TABLE I. Coefficients in the equation $Y=a_0+a_1P_1+a_2P_2+a_3P_3+a_4P_4+a_5P_5+a_6P_6$ to obtain the best fit of the experimental distributions.

Curve	a_0	a_1	a_2	a_3	a_4	a_5	a_6
Ground state							
3.06 Mev	1.36	0.05	0 98	0.41	0.07	−0.17	−0.45
2.84 Mev	1.41	0.25	1.02	0.53	−0.03	−0.17	−0.38
2.59 Mev	1.55	0.10	1.51	0.19	0.28	−0.05	−0.57
2.08 Mev	1.94	0.34	2.08	−0.12	−0.06	−0.07	−0.63
1.50 Mev	1.41	0.35	0.82	−0.14	−0.17	−0.06	−0.63
Excited state							
3.06 Mev	0.98	−0.10	−0.10	−0.10	−0.10	0.02	−0.09
2.59 Mev	1.01	0.08	−0.05	−0.23	−0.11	0.09	−0.18
2.08 Mev	0.97	0.15	−0.08	−0.12	−0.01	0.35	−0.10
1.49 Mev	0.90	0.12	−0.26	0.05	−0.09	−0.03	−0.06

(The solid angle correction at 30° was approximately 1 percent and was not applied.) The angle of observation in the center of mass system, θ', is obtained from the relation $\sin(\theta'-\theta)=(V_m/V_p')\sin\theta$, where V_m is the velocity of the center of mass and V_p' is the velocity of the emitted proton in the center of mass system. The yield in the center of mass system is obtained by multiplying the laboratory system yield by the factor $g(\theta)$ for the ratio of the solid angle subtended in the laboratory system to that subtended in the center of mass system, where $g(\theta)=\cos(\theta'-\theta)(\sin^2\theta/\sin^2\theta')$.

RESULTS

The results obtained are given in Fig. 2, where the yield relative to that obtained at 90° is plotted against the cosine of the angle in the center of mass system. It will be noted that the protons emitted in the formation of the excited state are essentially spherically symmetric at all energies, while those emitted in the formation of the ground state in general show an increased intensity in the forward direction. The data were analyzed in terms of Legendre polynomials out to P_6 by the method of numerical integration described by Taschek and

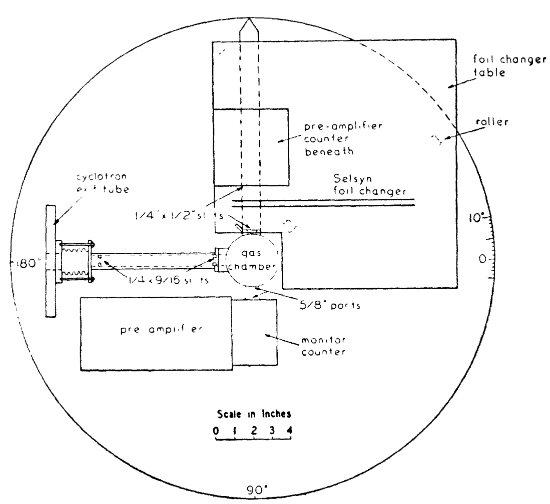

FIG. 1. Schematic diagram of equipment used in study of angular distribution of protons emitted in the $N^{14}(dp)N^{15}$ reaction.

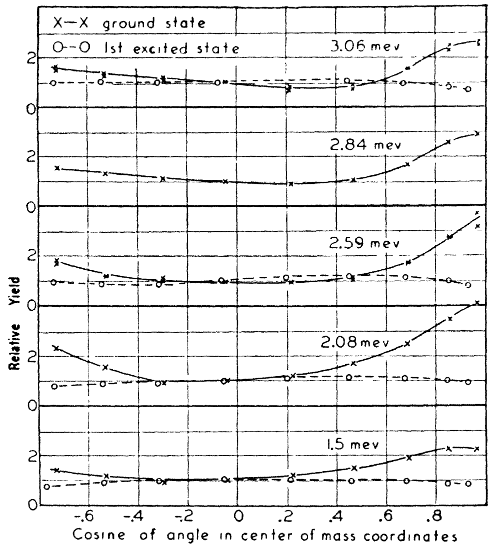

FIG. 2. Variation of yield of protons in the center of mass system as a function of the cosine of the angle for various bombarding energies.

Hemmendinger.[7] The coefficients so determined are given in Table I. However, if it is assumed that the 2.59-Mev curve is symmetric with respect to $\cos\theta' = 0$, it is found that within the accuracy of this assumption, the 2.59-Mev curve is represented by the expression: $Y = 1 - 0.22 \cos^2\theta' + 3.44 \cos^4\theta'$.

At the lower bombarding energies, where aluminum foils were introduced in the path of the beam, the neutron background increased, accounting for nearly 40 percent of the recorded count near 135° in the case of the 1.5-Mev ground state curve. In all other cases the background was less than 20 percent of the recorded counts. It should also be pointed out that no appreciable change in the neutron background as a function of angle was noted (except for that attributed to the aluminum foils in the beam), and thus it is concluded that the cross section for the $N^{14}(dn)O^{15}$ reaction is small. The data obtained for repeated runs of the 3.06-Mev and 2.59-Mev ground state curves are shown; good agreement was obtained except at 15° in the 2.59-Mev curve as shown. It should be noted that the normal beam spread of ±0.1 Mev is increased at small angles due to the increased target thickness (being approximately ±0.18 Mev at 30° for 2.25-Mev deuterons). The use of aluminum foil to reduce the beam energy also introduces a slight additional spread, at the lower energies, due to straggling.

The primary source of error in the experiments lay in the possible drift in the counting level of the circuits of either counter. In order to detect any change, the length of time for the standard number of monitor counts was always recorded together with the estimated beam in order to check the constancy of the monitor counter. In order to verify the reliability of the movable counter, frequent checks were made on the number of counts received at 90°. If any shift in counting levels was detected, the levels were readjusted and all of the data were repeated.

In these experiments, the compound nucleus is formed in a high state of excitation, approximately 22 Mev. The absence of any appreciable resonance is evident from the consistency of the two sets of curves as a function of energy, suggesting that at this state of excitation the energy level spacing in the compound nucleus is less than the energy spread of the bombarding deuterons. The lack of appreciable variation of the angular distributions with energy in this reaction can be compared to the results of Heydenburg and Inglis,[1] where pronounced changes in the distribution are observed; in their case the excitation of the compound nucleus F^{18} was about 9 Mev.

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[7] R. Taschek and A. Hemmendinger, Phys. Rev. **74**, 373 (1948).