PHYSICAL REVIEW VOLUME 112, NUMBER 6 DECEMBER 15, 1958

Angular Distributions from Deuteron Bombardment of Beryllium and Boron*

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(Received May 8, 1958)

The angular distributions, from 10° to 160°, of the emergent particles from the reactions $Be^9(d,p)Be^{10,10*}$, $B^{10}(d,p)B^{11,11*}$, and $B^{11}(d,n)C^{12,12*}$ have been investigated. The proton distributions were obtained at incident deuteron energies of 10, 9.2, and 8.1 Mev while the neutron distributions were obtained with 10-Mev deuterons. The proton distributions are analyzed using the Butler theory of deuteron stripping and, with the exception of the distributions from B^{11*}, are in agreement with $l_n=1$ at forward angles. The distributions from the first excited state of B^{11} are not in agreement with any curves based upon the Butler theory, indicating that stripping does not play a major part in this reaction. The neutron distributions are analyzed using the treatment of Owen and Madansky, which allows heavy-particle stripping as well as Butler stripping. Reasonable agreement between the data and this theory for the ground state is obtained by using approximately equal amplitudes for Butler and exchange stripping and angular momenta of $l=1$ and $l=0$, respectively, for deuteron and exchange stripping. The analysis of the distribution for the first excited state of C^{12} shows $l=1$ for deuteron stripping, but does not provide a unique choice for the angular momentum in exchange stripping.

INTRODUCTION

THE study of the angular distributions at forward angles for emergent particles from (d,p) and (d,n) reactions at intermediate energies has provided a considerable amount of useful information. When these distributions are analyzed in terms of deuteron stripping theory, limits upon the spins and parities of the final nuclear states can be set. A number of authors[1–7] have treated the problem, making use of different assumptions and formalisms, and have obtained similar results. In all cases, the theoretical treatments predict forward peaks with a rapid decrease in intensity at angles larger than that of the primary peak. Recently, studies of the reaction $B^{11}(d,n)C^{12}$, in which the angular distributions were extended beyond 90°, showed a significant contribution at backward angles.[8] Owen and Madansky[9] proposed that the nucleon detected at large angles may have originated in the target nucleus, rather than in the incident deuteron. This mechanism, heavy-particle stripping, predicts significant contributions to the differential cross section at backward angles. The treatment is patterned after the method of Bhatia[2] and includes both deuteron and exchange stripping and allows interference between the two mechanisms. Using the Born approximation and employing antisymmetrical wave functions for the outermost neutron in the boron nucleus they obtain, after a sum over the spins, a differential cross section of the form

$$\frac{d\sigma}{d\omega}\propto\left|G_d(K_1)j_1(k_1R_1)+\frac{\Lambda_2}{\Lambda_1}G_H(K_2)j_0(k_2R_2)\right|^2, \tag{1}$$

where the quantities in the matrix element are

$$K_1=[k_n^2+\tfrac{1}{4}k_d^2-k_nk_d\cos\theta]^{\frac{1}{2}},$$

$$k_1=\{k_d^2+[(11/12)k_n]^2-(11/6)k_nk_d\cos\theta\}^{\frac{1}{2}},$$

$$K_2=\{k_n^2+[(1/11)k_d]^2+(2/11)k_nk_d\cos\theta\}^{\frac{1}{2}},$$

$$k_2=[k_d^2+(\tfrac{1}{6}k_n)^2+\tfrac{1}{3}k_nk_d\cos\theta]^{\frac{1}{2}},$$

$$G_d(K_1)\propto\frac{2(2\pi\alpha_d)^{\frac{1}{2}}}{\alpha_d^2+K_1^2},$$

$$G_H(K_2)\propto\left\{\frac{\alpha_B^2}{\alpha_B^2-K_2^2}+\frac{1.9\beta_B^2}{\beta_B^2+K_2^2}\right\}\times[0.535\sin(K_2r_B)+j_1(K_2r_B)].$$

The $j_l(kR)$ terms are the spherical Bessel function of order $(l+\frac{1}{2})$ and k_n and k_d are the wave numbers (center-of-mass system) for the outgoing neutron and incident deuteron. The quotient Λ_2/Λ_1 gives the ratio of heavy-particle stripping to deuteron stripping and is treated as an adjustable parameter. The $B^{11}(d,n)C^{12}$ reaction has previously been investigated and analyzed in this manner for incident deuteron energies from 0.6 to 4.7 Mev and the experimental distributions are in good agreement with the theory. In the present work, the reaction was investigated and analyzed at 10 Mev to extend the range of measurements, as a test of the effectiveness of the heavy-particle stripping theory, and thus to determine the relative importance of the two mechanisms. In order to observe the effects of heavy-particle stripping in other reactions, the angular distributions from the reactions $Be^9(d,p)Be^{10,10*}$ and

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* Supported in part by the U. S. Air Force through the Office of Scientific Research of the Air Force Research and Development Command.

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$B^{10}(d,p)B^{11,11*}$ were investigated at incident deuteron energies of 10, 9.2, and 8.1 Mev. Heavy-particle stripping should be most apparent in a nucleus where the last proton or neutron is loosely bound. The fifth proton in B^{10} has a binding energy of 8 Mev as compared with a binding energy of 15 Mev for the fourth proton in Be^9, so that comparison of the angular distributions of protons from the (d,p) reactions on the two nuclei should indicate the effects of heavy-particle stripping. An investigation of the reaction $B^{10}(d,p)B^{11*}$ has the feature of providing additional information concerning the spin of the first excited state of B^{11}. Theoretical calculations[10,11] of the level structure lead to the expectation that the spin and parity of this state is $\frac{1}{2}^-$. Measurement of the lifetime of the state by Wilkinson,[12] Thirion's[13] determination of the angular correlation of the gamma rays from the reaction $B^{10}(d,p)B^{11*}(\gamma)B^{11}$, and a determination of the angular distribution of gamma rays following inelastic proton scattering from this level by Bair *et al.*[14] have confirmed this prediction. Work by Evans and Parkinson,[15] who have investigated the angular distributions of protons from the (d,p) reaction on B^{10} at deuteron energies ranging from 6.1 to 8.1 Mev, indicated some agreement between the Butler curves for $l=1$ and the distributions from the first excited state of B^{11}. This would set a lower limit of $\frac{3}{2}^-$ for the spin and parity of this state. Recently, Lee and Wall[16] have reported agreement with the Butler curve for $l=2$ at a deuteron energy of 14.3 Mev. This satisfies the angular momentum requirements, but leads to a positive parity for the state. The present work attempts to remove the apparent disagreement between the possible values of the spin predicted by stripping processes and the values of the spin as determined by other methods of investigation.

EXPERIMENTAL ARRANGEMENT

A. Beam and Energy Variation

The Washington University 45-in. cyclotron provides an external deuteron beam of 10-Mev energy. Since the beam fans out in the fringing field of the cyclotron, a pair of strong-focusing quadrupole magnetic lenses, five feet from the collimating slits at the exit position, afford an eightfold increase in intensity 20 feet from the exit slits. The beam enters the scattering chamber through a $\frac{9}{16}$-in. hole in a bismuth collimator, so that the effective area of bombardment on the target is a circle $\frac{1}{4}$in. in diameter. In order to obtain the 9.2-Mev beam, 16 mg/cm^2 of Al foil was placed directly after the slit system of the cyclotron. In addition to lowering the energy, the foil increased the energy spread of the beam and decreased the intensity on the target by an order of magnitude. The 8.1-Mev beam was obtained by focusing the 10-Mev beam upon the bismuth collimator and inserting 31 mg/cm^2 of aluminum in that position. The resultant intensity was again an order of magnitude lower and the energy spread greater. The 8.1-Mev beam was collimated so that the effective area of bombardment was a circle $\frac{3}{8}$ in. in diameter.

B. Scattering Chamber

The scattering chamber was a pillbox 16 in. in diameter and 5 in. deep. The side walls were $\frac{1}{2}$-in. brass; the top and bottom were steel plates $\frac{1}{2}$-in. thick; $\frac{3}{4}$-in. circular ports were cut in the side wall of the chamber. On one side, the ports were spaced at 10° intervals from 10° to 90° and at 20° intervals from 90° to 150° with a port at 160°. On the other side, the ports were spaced at 10° intervals from 15° to 85° and at 20° intervals from 100° to 140° with an additional port at 155°. Thin aluminum foils with a surface density of 20 mg/cm^2 covered the ports from 10° to 130°, while 10-mg/cm^2 foils covered the ports from 140° to 160°.

C. Targets

Three targets were used in the experiment. The beryllium target was a foil 1 mil thick and $1\frac{1}{16}$ in. in diameter. It showed evidence of oxygen contamination in addition to the single stable isotope of beryllium. The boron targets were prepared from enriched isotopes which were in the form of a "metallic" powder. For the B^{10} target, a water suspension of the powder was allowed to settle onto a $\frac{1}{4}$-mil polyethylene foil, leaving a fairly uniform target with a surface density of ~ 3 mg/cm^2. Targets prepared in this manner retained their uniformity, losing only a small amount of target material under sustained bombardment by deuteron beams of the order of 0.1 μa, but deteriorated rapidly when much higher beam intensities were employed. Since intense beams, of the order of 1 μa, were required for the neutron work, a backing of 0.1-mil nickel foil was used. A suspension of the B^{11} powder in polystyrene *Q*-dope thinner was prepared and a very small amount of polystyrene *Q*-dope was added to the suspension to serve as a binder. The suspension was then allowed to settle out onto the nickel foil as the liquid evaporated, leaving a uniform target 6 mg/cm^2 thick. After the initial deterioration, there was no noticeable change in the target throughout the entire course of bombardment.

D. Proton and Neutron Detection

The detector was a proton spectrometer modeled after that of Trail and Johnson,[17] modified so as to detect protons directly. A longitudinal cross section of the detector is shown in Fig. 1. Protons enter a thin

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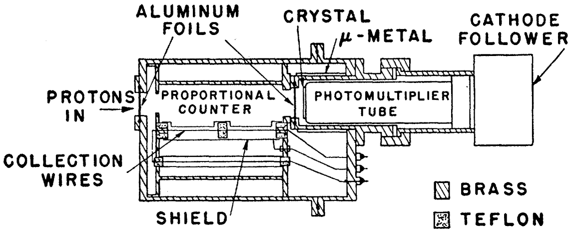

FIG. 1. Longitudinal cross section of the detector when used for neutron detection.

foil above the axis of the proportional counter section, pass through the proportional counter, and are stopped in the scintillation crystal. When neutrons are being detected, appropriate foils prevented all charged particles from reaching the detector. A polyethylene radiator was placed directly before the counter and the recoil protons from the radiator were detected in the same fashion as for direct detection of protons. When a 40-mg/cm^2 polyethylene radiator was used, the efficiency for neutron detection was 1.75×10^{-5} times the numerical value of the *n-p* scattering cross section measured in barns.

The proportional counter was filled with a mixture of 90% argon, 10% CO_2 at a pressure of 14 cm Hg. A section of a cylindrical shield (whose voltage corresponded to the undistorted field at the same position) covered a 240° angle and effectively limited the active volume of the counter to the region through which the protons passed. For the (d,p) investigation, a single collection wire of 3-mil tungsten was used, while for the (d,n) reactions the wire was separated into two parts, and in the region where the two wires met, the shield covered the full 360°. This provided two proportional counters having no partition between them, with the radial symmetry of the field being maintained throughout almost the entire volume of the counter. For the (d,p) investigations, the scintillation counter consisted of a CsI(Tl) crystal 1 mm thick mounted on a Dumont 6291 photomultiplier tube. For the (d,n) work, a NaI(Tl) crystal 2 mm thick was used.

Identification of the proton groups was made in the scintillation counter. By requiring a coincidence between the pulses from the proportional counter and the scintillator, with appropriate delays to account for the differing response times, the proton groups were isolated. The use of thin crystals required the insertion of additional absorbers in front of the detector in order to insure that the protons would stop in the crystal. In addition to stopping elastically scattered deuterons, the absorber also improved the effective resolution of the detector. Because the energy loss per unit path length for charged particles varies inversely as the velocity, proton groups initially differing in energy are further separated in energy after passing through the absorbers. With the absorbers used, the detector had about 6% resolution for the proton work. The width of the observed peaks was increased by the thickness of the target and, in the case of neutron detection, by the thickness of the radiator.

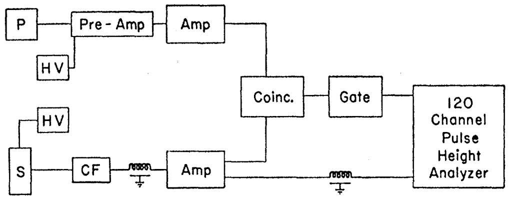

FIG. 2. Block diagram of electronic system: *P* one section of proportional counter; *S* scintillation counter. When the proportional counter was used in two sections, a similar counter-amplifier sequence was connected in parallel.

E. Electronics

A block diagram of the electronic system is shown in Fig. 2. The pulses from the proportional counters were fed into preamplifiers and then into linear amplifiers. The pulses from the scintillator were sent into a cathode follower and, after being delayed to bring them into coincidence with the proportional counter pulses, were also fed into a linear amplifier. The pulses from the discriminator output of the amplifiers were sent into a coincidence circuit which was operated with a resolving time of 1.5 μsec. The output of the coincidence circuit gated a multi-channel pulse-height analyzer to accept the delayed pulse from the scintillation counter. The multi-channel analyzer uses pulse-height-to-time conversion as in the design developed by Hutchinson and Scarrott.[18]

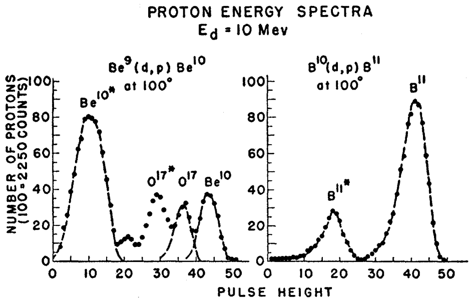

FIG. 3. Proton energy spectra at 100°. The indicated pulse height represents channel number on the analyzer. Since a biased amplifier is incorporated into the analyzer, zero pulse height would correspond to a large negative number.

F. Monitoring

Normalization of the runs at each angle was performed by a monitor consisting of a double proportional-counter coincidence telescope fixed at an angle of 35° to the beam. Absorbers were placed in front of the monitor and bias levels on the coincidence circuit were set so that only protons which stopped in the second

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chamber were counted. In this way, only protons of a specified energy resulting from one of the (d,p) reactions in the target were detected. To avoid systematic errors resulting from changes in bias levels, etc., the runs at the various angles were made in random order.

G. Analysis of the Data

The spectra of the protons from the reaction $Be^9(d,p)Be^{10}$ and $B^{10}(d,p)B^{11}$ at 100° are shown in Fig. 3. The spectra from the $Be^9(d,p)Be^{10}$ reaction included protons from oxygen present as a contaminant. By taking an independent angular distribution for the reaction $O^{16}(d,p)O^{17}$, this contaminant could be subtracted from the spectra. One sees that the general background is quite low.

The angular distributions for the (d,p) reactions were obtained by integrating the area under the peaks, normalizing to a fixed number of monitor counts, and then transforming intensities and angles from laboratory to center-of-mass coordinates.

For the (d,n) work, the number of counts at each angle was much lower so that the observed intensities at each angle were obtained by simply adding the number of counts in each group. Since the neutron detector had an efficiency $\sim 10^{-5}$ times that of the proton detector, the background from chance coincidences was important here. The primary source of background was the high gamma-ray background from the target. In order to determine this background, a run with the radiator in position for neutron detection was made and, immediately afterward, the run was repeated under the same conditions, but with the radiator removed. This second run gave the number of counts from all sources except the radiator. The number of recoil protons was given by the difference in counts between the two runs over the energy interval covered by the group being observed. The observed neutron spectrum at 20° is shown as Fig. 4(a). At forward angles the energy separation between the ground state and the first excited state was so large that they could not be observed simultaneously. At backward angles they could both be observed, as is shown in Fig. 4(b).

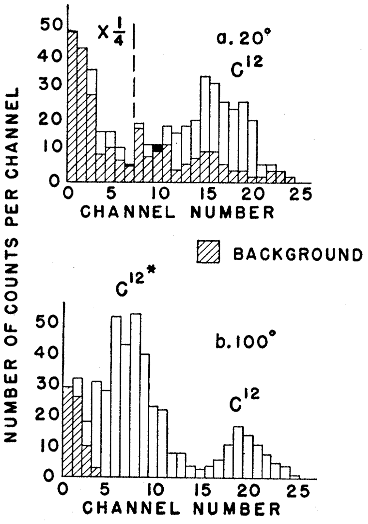


FIG. 4. Neutron energy spectra from $B^{11}(d,n)C^{12}$.

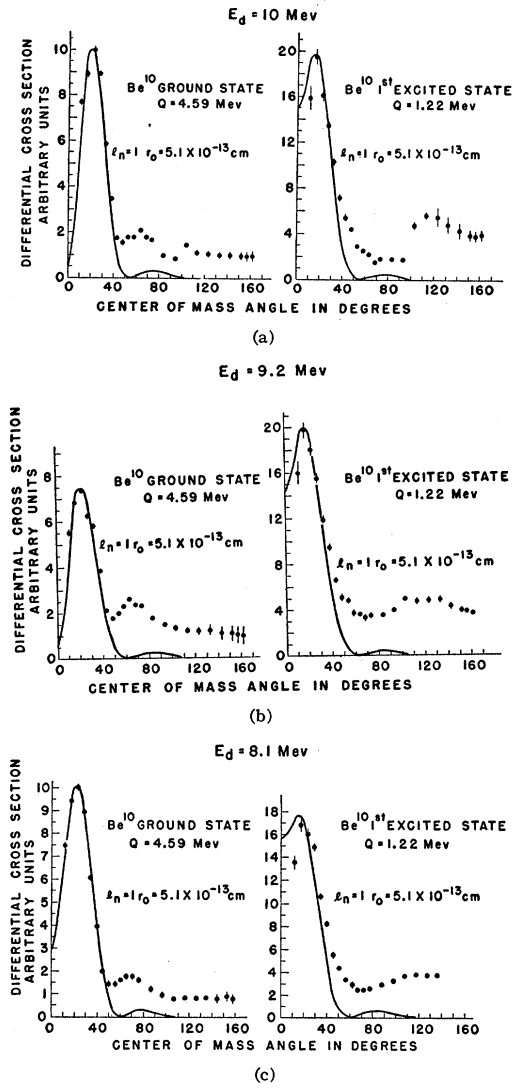


FIG. 5. Angular distributions from $Be^9(d,p)Be^{10}$: (a) $E_d=10$ Mev, (b) $E_d=9.2$ Mev, (c) $E_d=8.1$ Mev. The curves are calculated from Butler's stripping theory.

The (d,n) data were handled in the same manner as the (d,p) data except for an additional correction to take into account the energy dependence of the n-p scattering cross section.

RESULTS AND DISCUSSION

A. Proton Distributions

$Be^9(d,p)Be^{10}$

The angular distributions of protons from the ground state and first excited state of Be^{10}, produced by bombardment of Be^9 with the deuterons of energies

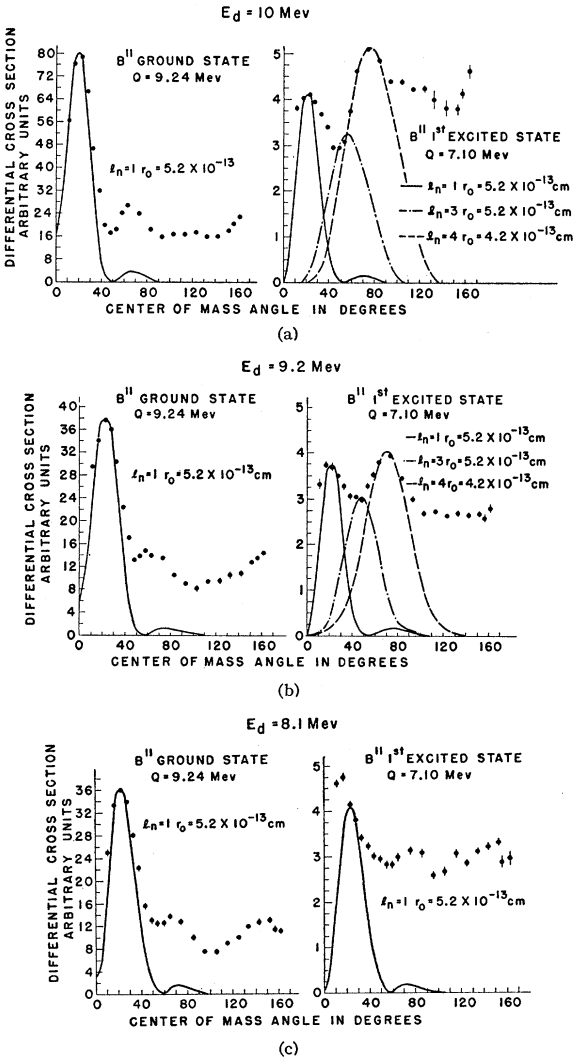
10.0, 9.2, and 8.1 Mev, are shown in Figs. 5(a), 5(b), and 5(c). The differential cross sections for both states are plotted in the same units so that comparison, at a given energy, can be made directly from the ordinates. The errors shown are an estimate of the possible systematic errors; the primary source being the subtraction of the contribution from the oxygen contaminant. Statistical errors are small compared to these possible systematic errors. The angular distributions from the excited state also show the forward stripping peak. At 110° is a second weaker peak, which is not accounted for in the Butler theory and is strongly energy dependent. At forward angles, the distributions of both groups are well fitted by the theoretical Butler curves for $l=1$, using a radius of 5.1×10^{-13} cm. Comparison of the intensities at different energies can not be made since no absolute cross sections were measured. The angular distributions from the reaction $\mathrm{Be}^9(d,p)\mathrm{Be}^{10}$ have previously been investigated over a wide energy range by a number of authors.[19–24] The work at an energy most nearly approximating that used in the present experiment is that of El-Bedewi.[25] Using 7.7-Mev deuterons, he found distributions in excellent agreement with the present results. Since the distinct peak which occurs at 110° in the distribution for the excited state seems to be strongly energy dependent both in shape and intensity, one would suspect that it is the result of interference effects. A similar peak has been observed in O^{17} by Burrows *et al.*[26]

$B^{10}(d,p)\mathrm{B}^{11}$

The angular distributions of protons from the ground state and first excited state of B^{11} produced by bombardment of B^{10} with deuterons of energies 10, 9.2, and 8.1 Mev are shown in Figs. 6(a), 6(b), and 6(c). The relative differential cross sections for the ground state and first excited state at a given energy can be compared from the ordinates. The error bars on the points again indicate an estimate of the possible systematic errors. The angular distribution from the ground state all show well-defined deuteron-stripping peaks which are adequately fitted by the theoretical Butler curves for $l=1$ using a radius of 5.2×10^{-13} cm. The distributions for the excited state, however, show marked variation with deuteron energy and are not in agreement with any Butler curves.

The present work is in agreement with the angular distributions obtained by Evans and Parkinson[15] at 7.7 Mev. The trends noted in the present work are continued in their observations. At 7.7 Mev, the distribution for the excited state shows no trace of the peak at 70°, as would be expected from its rapid decrease in intensity over the energy range covered in the present investigation. The distribution shows a slight rise at backward angles, and the forward peak continues the trend of peaking nearer to 0° as the energy decreases.

The lack of agreement between the Butler curves and the distributions for the excited state is not too surprising. Since the spin and parity of B^{10} is 3^+ and that expected for B^{11} is $\frac{1}{2}^-$, the conservation of angular momentum and parity requires $l_n=3, 5\ldots$ The theoretical calculations of the level structure[10,11] have been made under the assumption that the low-lying states can be described purely in terms of excitation within the p state. In deuteron stripping, the additional



(a)

(b)

(c)

FIG. 6. Angular distributions from $\mathrm{B}^{10}(d,p)\mathrm{B}^{11}$: (a) $E_d=10$ Mev, (b) $E_d=9.2$ Mev, (c) $E_d=8.1$ Mev. The curves are calculated from Butler's stripping theory.

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nucleon is accepted into the target nucleus in a definite state of angular momentum, so that for $l=3$, the neutron added to the B^{10} nucleus to form B^{11} in its first excited state would be in an f state. It is therefore improbable that the state can be formed in a deuteron-stripping process. The low cross section for the state is consistent with this conclusion. In view of the strong energy dependence of the shape of the distribution, it seems probable that the agreement between the Butler curve for $l=2$ and the data at 14.3 Mev is purely accidental.[16]

Inasmuch as there is some tendency toward agreement between a curve for $l=1$ and the observed distributions for the excited state, the possibility of another mechanism, spin-flip stripping, has been discussed.[12,15] This process is essentially deuteron stripping, but as the proton leaves the target nucleus, an interaction between the two flips the spin of the proton, thereby providing an additional unit of angular momentum. In this way, it is possible for the neutron to be accepted into the nucleus in a p state and still conserve angular momentum. An investigation of the polarization of protons from the reaction $B^{10}(d,p)B^{11*}$ has shown the sign of polarization to be consistent with this mechanism.[27] Evans and French[28] have recently made a calculation in which nucleon exchange in the $B^{10}(d,p)B^{11}$ reaction is considered. Their results are in fair agreement with the data at 8.1 Mev, but fail to predict the strong peak in the vicinity of 70° that is exhibited by the data for 9.2 and 10 Mev. It should be noted that this treatment differs markedly from the "heavy particle" treatment.

Although no quantitative calculations concerning the presence of a contribution from heavy-particle stripping have been made, the features of the distributions allow several inferences to be drawn. Comparison of the distributions from the ground states of Be^{10} and B^{11} indicate that the expectation of relative enhancement of exchange stripping in B^{11} is justified. The isotropy of the "background" for the ground-state distributions of Be^{10} implies that heavy-particle stripping is probably of little importance. No attempt has been made to fit the data with theoretical distributions. The angular distributions from the ground state of B^{11} show strong deviations from isotropy at backward angles, however, and these shapes seem energy dependent. Since the angular distributions from compound-nucleus formation are essentially isotropic at the deuteron energies involved, the observed distributions indicate the influence of another mechanism, which may be heavy-particle stripping.

B. Neutron Distributions

The angular distributions of neutrons from the reactions $B^{11}(d,n)C^{12,12*}$ are shown in Fig. 7. The energy of the incident deuterons was 10 Mev. Comparison of the relative intensities of the ground state and first excited state can be made directly from the ordinates. The errors in the neutron data are the statistical errors resulting from the low counting rate and subtraction of the background.

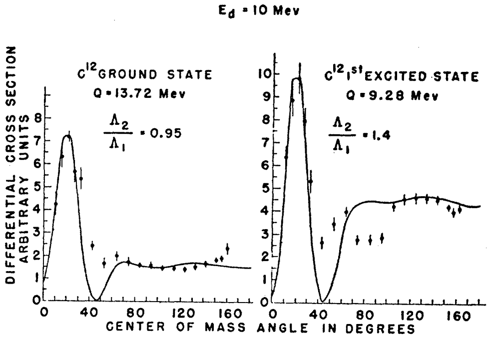

FIG. 7. Angular distributions from $B^{11}(d,n)C^{12}$ at 10 Mev. The curves are calculated from the Owen-Madansky stripping theory. In both cases $R_1=R_2=5.9\times10^{-13}$ cm, $l_p=1$, $l_c=0$. The ratios between deuteron and heavy-particle stripping theory are shown in the figure.

The angular distributions of both states show the strong forward peak characteristic of deuteron stripping with $l=1$, as had been found previously by Maslin *et al.* for 9-Mev deuterons.[29] By the use of Eq. (1), the differential cross section for heavy-particle stripping, the fit was attenpted for the ground state and is shown as a solid curve in Fig. 7. With the parameters shown, the curve is in qualitative agreement with the data. At lower energies, Owen and Madansky[9] have fitted the same reaction and their choice of $l=0$ for heavy-particle stripping with $\Lambda_1/\Lambda_2\approx1$ is in good agreement with the parameters used in this distribution.

The fit to the distribution for the excited state, shown as a solid curve in Fig. 7, is not as impressive as that for the ground state. A backward peak is predicted and present in the observed data; but there is a peak at 60°, which is not accounted for by the theory. Several variations of the parameters for heavy-particle stripping were employed with no improvement. Considering the rough nature of the derivation of the differential cross section and the generality of the assumptions employed, the agreement is probably as good as could be expected.

SUMMARY AND CONCLUSIONS

The present work has presented further evidence that the dominant mechanism involved in the (d,p) reaction forming the first excited state of B^{11} is not deuteron stripping. The low relative cross section, the energy dependence of the angular distributions, and the general poor fit of the standard stripping distributions are all evidence of this. Since the assignment of the value $l=1$ cannot now be justified, the assignment

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of $\frac{1}{2}^-$ for the spin and parity of this level is not excluded. Since the mechanism which is usually most probable is apparently not allowed, one must consider less probable ones, such as spin-flip, heavy-particle stripping, and, of course, compound-nucleus formation and interference between the various mechanisms.

The experimental data considered for evidence of heavy-particle stripping give some useful results. As one would qualitatively expect in the contribution from heavy-particle stripping, there is more anisotropy in the angular distributions of the protons from the $B^{10}(d,p)B^{11}$ reaction, in which the last proton is more loosely bound, then from the $Be^9(d,p)Be^{10}$ reaction. The agreement of the $B^{11}(d,n)C^{12}$ data with the theory now provides an energy region from 0.6 Mev to 10 Mev over which this reaction is fitted by the heavy-particle stripping theory, with only the radius of interaction as a variable parameter. Since this parameter must simulate the various distortions of the wave functions, which are certainly energy dependent, it does not seem unreasonable that it should vary, as it does, from 3.8×10^{-13} cm for the low-energy data to 5.9×10^{-13} for the present data. The success of this crude theory in this reaction indicates that the heavy-particle stripping mechanism must be considered as an important contribution to the stripping reactions.

ACKNOWLEDGMENT

The authors wish to acknowledge the benefits of stimulating discussions with Professor George E. Owen of the Johns Hopkins University and also the cooperation of the staff of the Washington University cyclotron in obtaining the data.

PHYSICAL REVIEW VOLUME 112, NUMBER 6 DECEMBER 15, 1958

Internal Conversion Electrons from Coulomb Excitation of Ta^{181}†

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(Received March 31, 1958)

The conversion electron spectrum following Coulomb excitation of Ta^{181} has been remeasured with greater accuracy. The results are internally consistent with the rotational model of Bohr and Mottleson and are in excellent agreement with the gamma-ray angular distribution and yield data of McGowan and Stelson.

INTRODUCTION

COULOMB excitation of highly deformed odd-A nuclei offers an excellent means of testing the rotational model of Bohr and Mottelson,[1] since one can excite the first two rotational states above the ground state. Thus, one can compare the ratio of the energies of the states, the reduced transition probabilities for exciting the two levels, and the $E2$ to $M1$ mixing ratios for the first rotational state transition and the cascade transition from the second to the first rotational state.

The most extensive measurements[2–8] of the quantities mentioned above have been made for Ta^{181}. In particular, McGowan and Stelson[7] have made accurate measurements of the yields and angular distributions of the gamma-rays following Coulomb excitation of the first two rotational states above the ground state. The results of these measurements are in good agreement with the theoretical predictions. The previous conversion electron experiments[8,9] seemed to indicate somewhat smaller $E2$ to $M1$ mixing ratios than the gamma-ray experiments; however, the experimental uncertainties were quite large.

The conversion electron spectrum following Coulomb excitation of Ta^{181} has been remeasured with greater accuracy, particularly for the cascade transition. The results are in good agreement with the theory and the gamma-ray results.

EXPERIMENTAL PROCEDURE

The experimental arrangement has been described previously.[8] The only change has been to replace the Geiger counter by an anthracene scintillation counter. This reduced background from the accelerator and also

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† This work was supported by the U. S. Atomic Energy Commission.

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