P and coupled $^3F_2$. A mechanism to suppress the scattering associated with the nonpolarizing phases would increase the polarization. Since at this energy the impact parameters for angular momenta of 2–3$\hbar$ become as large as one half the internucleon spacing, the higher waves are more probably associated with momentum transfers to more than one nucleon and thus would not yield protons in the top energy range we selected. Modification of the $^3F_2$ phase by this process might also effect the polarization.

Recent reports by Dickson and Salter[24] and by Marshall, Marshall, and Nedzel[25] cover polarization experiments in which no large effects were found.

XI. ACKNOWLEDGMENTS

We gratefully acknowledge the cooperation and assistance of E. Baskir, D. Klein, J. W. Ring, and W. A. Skillman during the course of the experiment. J. O. Dungan engineered the mechanical construction of the apparatus. We are indebted to Professor S. W. Barnes and several other colleagues at the University of Rochester and elsewhere for helpful discussions and encouragement.

[24] J. M. Dickson and D. C. Salter, Proc. Phys. Soc. (London) **A66**, 721 (1953).

[25] Marshall, Marshall, and Nedzel, Phys. Rev. **92**, 834 (1953).

PHYSICAL REVIEW VOLUME 93, NUMBER 4 FEBRUARY 15, 1954

Angular Distribution of Protons from the Reaction $B^{10}(d,p)B^{11}$†

WILLIAM W. PRATT
Department of Physics, State University of Iowa, Iowa City, Iowa

(Received October 26, 1953)

The angular distributions of the four longest-range proton groups have been measured in the forward direction using a nuclear plate scattering chamber. The deuteron energy was 3.03 Mev. The observed angular distributions were not in agreement with stripping theory, indicating a relatively large contribution from compound nuclear formation.

THE angular distribution of the protons emitted in the $B^{10}(d,p)B^{11}$ reaction has been measured for the four longest-range proton groups. The deuteron energy was 3.03 Mev in the laboratory system of coordinates. Previous measurements on these groups have been made by Endt *et al.*[1] at 0.31 Mev and on the longest-range group by Redman[2] at a variety of energies from 1.06 Mev to 3.68 Mev. It was the purpose of the present work to obtain angular distributions of all four proton groups in the forward direction at a sufficiently high deuteron energy to effect a comparison between the experimental data and the theoretical distributions predicted by Butler[3] for a stripping reaction.

A deuteron beam was obtained from the S.U.I. electrostatic generator. After passing through a magnetic analyzer and a suitable collimating system, the deuterons impinged on a thin target of enriched B^{10} evaporated onto a silver backing of 13.55 mg/cm^2 surface density. Protons from the (d,p) reaction passed through the silver backing into an Eastman NTA nuclear track plate whose surface was inclined at an angle of 5° with respect to the scattering plane. Silver and aluminum foils were inserted between the target and the plate in order to eliminate elastically scattered deuterons and to reduce the proton range in the emulsion to a convenient value (20 to 200 microns) for range measurements. The plates were scanned with a Spencer monocular microscope with a 4-mm achromatic objective and a 10× eyepiece with a calibrated eyepiece scale. It was possible by this method to separate the four proton groups and to determine the number of protons as a function of angle with respect to the direction of the incident deuteron beam.

The resulting angular distributions are shown in Fig. 1 together with the appropriate theoretical curves of Butler's theory.[3] The relative yields at 20° in decreasing order of Q value are 1:0.2:1.2:0.6. The normalization of the theoretical curves is arbitrary. The absence of agreement between the experimental data and the theoretical curves makes it impossible to determine the value of l_n, the orbital angular momentum of the captured neutron. It is customary[3–5] to attribute a lack of agreement between Butler's curves and the experimental data at least in part to the role played by compound nucleus formation (and subsequent proton emission) which is not accounted for in Butler's theory. In this connection it is of interest to consider the proton angular distributions at angles greater than 90°, where the contribution of stripping is presumably small. Figure 2a shows the present data on

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

[1] P. M. Endt *et al.*, Physica **18**, 423 (1952).

[2] W. C. Redman, Phys. Rev. **79**, 6 (1950).

[3] S. T. Butler, Proc. Roy. Soc. (London) **A208**, 559 (1951).

[4] Philip Shapiro, Phys. Rev. **93**, 290 (1954).

[5] W. E. Nickell, Phys. Rev. (to be published).

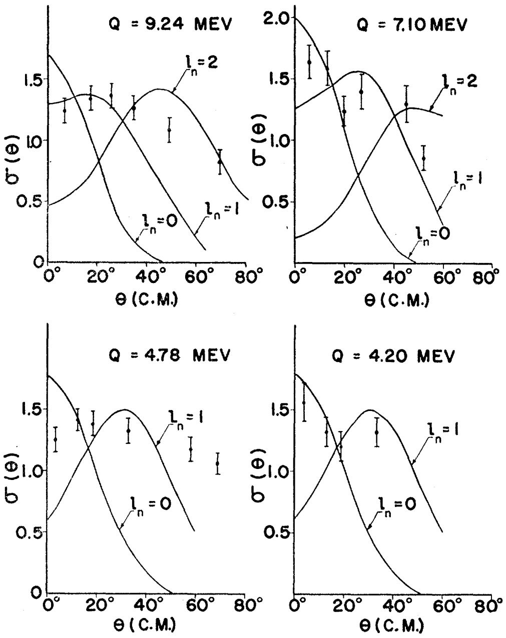

FIG. 1. The angular distribution of four proton groups. The differential cross sections $\sigma(\theta)$ are plotted on arbitrary scales as a function of the center-of-mass angle of scattering θ(C.M.). The errors indicated are statistical errors only.

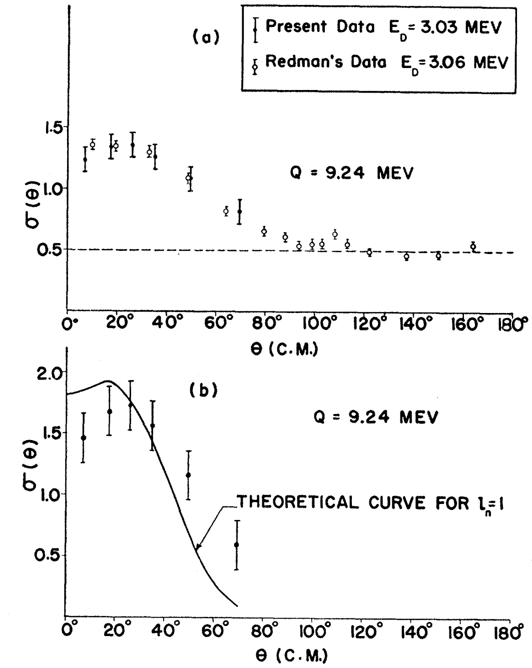

FIG. 2. (a) Comparison of the angular distribution of ground state protons as obtained in the present work with that obtained by Redman[2] at 3.06 Mev. The dotted line indicates the assumed contribution of compound nucleus formation. (b) Angular distribution of ground-state protons with the assumed contribution of compound nucleus formation subtracted. The errors indicated are statistical errors only.

the ground-state transition with that of Redman,[2] who obtained data out to 164°. If it is assumed that the dotted line represents a reasonable approximation to the contribution of compound nucleus formation, then an approximate correction for this effect may be obtained by subtracting this amount from each of the experimental points. This is done in Fig. 2b, and it is seen that the agreement between the experimental points and the theoretical curve for $l_n = 1$ is considerably improved.

B^{10} is known[6] to have a spin of 3 and even parity; and the ground state of B^{11} is known[6] to have a spin of $\frac{3}{2}$ and probably (according to the shell model[7]) odd parity. Thus the ground-state proton group would be expected to have a mixture of l_n values of 1, 3, and 5, with the lowest l_n value predominant.[3] The agreement in Fig. 2b could undoubtedly be improved by assuming a mixture of $l_n = 1$ and $l_n = 3$ for the theoretical curve, although the significance of any such agreement would be open to question.

The proton groups corresponding to the three excited states of B^{11} could presumably be treated in a similar manner, although no data are available at present on the angular distributions at large angles. It does, however, appear from the lack of agreement between the experimental data and Butler's curves that compound nuclear formation is an important effect in these cases also.

The writer is indebted to Professor James A. Jacobs, Philip Malmberg, Philip Shapiro, and W. E. Nickell for much assistance with this work.

[6] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **24**, 321 (1952).

[7] P. F. A. Klinkenberg, Revs. Modern Phys. **24**, 63 (1952).