Tensor Polarization of Deuterons from the $Be^9(p,d)Be^8$ Reaction*

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The second-rank tensor polarization parameters $\langle T_{2q}\rangle$ describing the deuterons produced in the $Be^9(p,d)Be^8$ reaction have been measured for average proton bombarding energies of 2.5 and 3.7 MeV. Measurements were taken at ten-degree intervals for six emission angles between 0° and 50° in the laboratory system. The tensor moments were determined by observing the polar and azimuthal angular dependence of the intensity of the protons from the $He^3(d,p)He^4$ reaction when this reaction is initiated by deuterons from the $Be^9(p,d)Be^8$ reaction. Similar results were obtained at both of the bombarding energies investigated. The $\langle T_{2q}\rangle$ are generally negative, with absolute magnitudes of the order of 0.20 or less. Preliminary calculations of the $\langle T_{2q}\rangle$ using the distorted-wave Born approximation with spin-orbit terms in the distorting potentials agree generally in sign with the measured values, but are consistently smaller than these by at least an order of magnitude.

I. INTRODUCTION

POLARIZATION measurements on the products of stripping and pickup reactions are of considerable importance for establishing the validity of current theories[1-3] of such reactions and delineating the parameters involved in these theories. In the distorted-wave Born approximation (DWBA) description of (p,d) reactions, only vector polarization of the outgoing deuterons will result if no spin-dependent interactions are assumed to be present,[1-3] since the polarization of the deuteron is produced entirely by the picked-up neutron. That spin-dependent interactions are of some importance, however, is indicated by the fact that substantial polarizations are observed in the elastic scattering of nucleons from nuclei, and from the fact that the magnitude of the nucleon polarization produced in deuteron stripping reactions has been observed to exceed the maximum value predicted when spin dependent interactions are neglected.[4] One of the consequences of including spin-dependent interactions in a DWBA description of the pickup reaction is that the outgoing deuterons will exhibit second-rank tensor polarization in addition to vector polarization. Experimental determination of this tensor polarization may provide a reasonably sensitive method for investigating the spin-dependent part of the interactions, within the framework of the particular model used to describe the reaction.

Differential cross-section measurements[5,6] on the $Be^9(p,d)Be^8$ ($Q=0.56$ MeV) reaction furnish compelling evidence for the direct nature of the reaction process in this case. Figure 1 shows the results of cross-section measurements by Weber *et al.*[5] for a proton energy of 2.84 MeV. Aside from a gradual narrowing of the forward peak with increasing bombarding energy, the cross section for angles less than about 60° does not change significantly over the proton energy range extending from 2.2 to about 8 MeV.

Two measurements of the vector polarization of the deuterons from the $Be^9(p,d)Be^8$ reaction have been reported. Lambert, Madansky, and Owen[7] measured the left-right asymmetry in the intensity of protons from the $D(d,p)H^3$ reaction when this reaction was initiated by deuterons from the $Be^9(p,d)Be^8$ reaction. Assuming both reactions to be describable by stripping theory without spin-dependent interactions, i.e., ignoring second-rank polarization effects, these authors obtained values of the vector polarization P_d of the order of +10% (Basel convention) for deuterons emitted at laboratory angles of 30° and 90° for an incident proton energy of 3 MeV. In a similar experiment carried out at a proton energy of 5 MeV, Bokhari and Verbinski[8] obtained values of P_d of the order of +5% at emission angles of 30° and 45°, and a value of about −3% at an emission angle of 60°. For these measurements the $C^{12}(d,p)C^{13}$ reaction was used as an analyzer. In both of these experiments, the validity of the results depends on the absence of any significant second-rank tensor moments, $\langle T_{2q}\rangle$, for either the deuterons being investigated or for the deuterons produced in the inverse of the analyzer reaction. This can be seen from the general expression for the cross section for a reaction induced by polarized deuterons[9]:

$$\frac{d\sigma}{d\omega}=\left(\frac{d\sigma}{d\omega}\right)_{\mathrm{unpol}}\Big[1+\sum_{k=1,2}\sum_{|q|\leq k}(-1)^{k+q}\langle T_{kq}\rangle\langle\mathcal{T}_{k-q}\rangle\Big]. \quad (1)$$

In this expression, the $\langle T_{kq}\rangle$ are the tensor moments

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1 G. R. Satchler, Nucl. Phys. **6**, 543 (1958).
2 G. L. Vysotskii and A. G. Sitenko, Zh. Eksperim. i Teor. Fiz. **36**, 1143 (1959) [English transl.: Soviet Phys.—JETP **9**, 812 (1959)].
3 L. J. Goldfarb and R. C. Johnson, Nucl. Phys. **18**, 353 (1960).
4 L. J. B. Goldfarb, in *Proceedings of the Rutherford Jubilee International Conference*, edited by J. B. Birks (Academic Press Inc., New York, 1961), pp. 479–490.
5 G. Weber, L. W. Davis, and J. B. Marion, Phys. Rev. **104**, 1307 (1956).
6 J. A. Harvey, Phys. Rev. **82**, 298 (1951).
7 J. M. Lambert, L. Madansky, and G. E. Owen, Phys. Rev. **124**, 1959 (1961).
8 M. S. Bokhari and V. V. Verbinski, Bull. Am. Phys. Soc. **9**, 627 (1964).
9 G. R. Satchler, Nucl. Phys. **8**, 65 (1958).

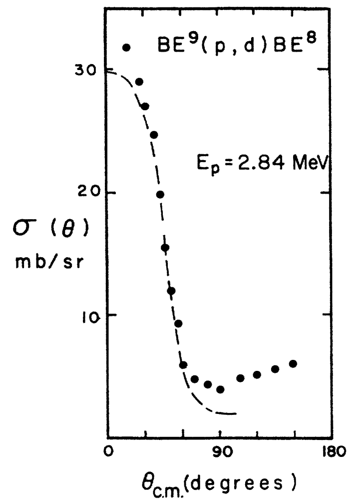

FIG. 1. Angular distribution of the deuterons from the $Be^9(p,d)Be^8$ reaction for a proton bombarding energy of 2.84 MeV. The data are from Ref. 5. The dashed curve is the result of the DWBA calculation discussed in the text.

describing the polarization state of the incident deuteron beam, and the $\langle \mathcal{T}_{kq}\rangle$ are the moments produced when the inverse of the reaction is induced by unpolarized particles. For the (p,d) reaction, choosing $\mathbf{k}_d$ as the z axis and $\mathbf{k}_p\times\mathbf{k}_d$ as the y axis, $\langle T_{2q}\rangle=(-1)^q \times\langle T_{2-q}\rangle$ and similarly for the $\langle \mathcal{T}_{2q}\rangle$. For this choice of axes the polarization state of the deuteron beam from the (p,d) reaction is described by the four real quantities, $i\langle T_{11}\rangle=\frac{1}{2}\sqrt{3}P_d$, $\langle T_{20}\rangle$, $\langle T_{21}\rangle$, and $\langle T_{22}\rangle$. The same holds for the $\langle \mathcal{T}_{2q}\rangle$. If the stripping theory without spin-dependent interactions is used, the $\langle T_{2q}\rangle$ and $\langle \mathcal{T}_{2q}\rangle$ vanish, and the vector polarization P_d can be obtained from a left-right asymmetry meaurement, providing the vector polarization of the protons produced when the analyzer reaction is initiated by unpolarized deuterons is known. It is clear from Eq. (1) that some knowledge of the $\langle T_{2q}\rangle$ and $\langle \mathcal{T}_{2q}\rangle$ is desirable from the standpoint of vector polarization measurements, in view of the aforementioned evidence for the importance of spin-dependent interactions in the reaction process.

In the experiment being reported here, the $\langle T_{2q}\rangle$ describing the deuterons emitted from the $Be^9(p,d)Be^8$ reaction have been determined for six laboratory emission angles between 0° and 50° at mean proton bombarding energies of 2.5 and 3.7 MeV.

II. EXPERIMENTAL METHOD

The procedure used to measure the $\langle T_{2q}\rangle$ was essentially the same as that used by Seiler *et al.*,[10] based on a method suggested by Galonsky, Willard, and Welton.[11] This method utilizes the fact that the angular distribution of protons from the $He^3(d,p)He^4$ reaction depends for sufficiently low deuteron energy, on the $\langle T_{2q}\rangle$ of the incident deuteron beam in a particularly simple way. For deuteron energies below about 1 MeV, the $He^3(d,p)He^4$ reaction is initiated almost entirely by s-wave deuterons, and proceeds mainly through a $\frac{3}{2}^+$ state in Li^5, the energy of which corresponds to a deuteron energy of about 340 keV. For polarized deuterons incident, the cross section for this reaction as given by Eq. (1) reduces to [12]

$$\sigma(\theta,\phi)=\sigma_0[1-\beta\{\tfrac{1}{4}\sqrt{2}\langle T_{20}\rangle(3\cos^2\theta-1) -\sqrt{3}\langle T_{21}\rangle\sin\theta\cos\theta\cos\phi+\tfrac{1}{2}\sqrt{3}\langle T_{22}\rangle\sin^2\theta\cos2\phi\}], \quad (2)$$

assuming only s-wave deuterons to be interacting. The $\langle T_{2q}\rangle$ describe the polarization of the incident beam and σ_0 is the cross section for unpolarized deuterons. Both the angles and the $\langle T_{2q}\rangle$ are referred to the coordinate system discussed in the introduction. The factor β is a real number which depends on the relative contributions of the two states, $J^\pi=\frac{3}{2}^+$ and $J^\pi=\frac{1}{2}^+$, through which the reaction can proceed when initiated by s-wave deuterons. If only the $J^\pi=\frac{3}{2}^+$ state were to contribute, β would be unity. Information on the value of β has been obtained by Brown, Christ, and Rudin[13] from measurements on the angular distribution of protons from the reaction when it is initiated by deuterons from a polarized ion source. The results of their measurements indicate that an appropriate value of β, averaged over deuteron energies below about 800 keV, is about 0.85.

Another result of the measurements of Brown *et al.*[13] is that no left-right asymmetry was observed in the protons emitted at 90° from this reaction when the incident deuterons were vector polarized perpendicularly to the reaction plane. This result suggests that no significant vector-polarization effects are introduced into this reaction by higher orbital angular-momentum contributions for deuteron energies below about 1 MeV. The reason for this is that the small anisotropy in the unpolarized cross-section[14] near 1 MeV appears to arise from the interference of incident s waves and p waves, and any vector-polarization effects produced by s-p interference would be observable at 90°.

From a measurement of $\sigma(\theta,\phi)$ at four different sets of angles, it is a straightforward matter to determine the $\langle T_{2q}\rangle$. In this experiment the $\langle T_{2q}\rangle$ for deuterons from the $Be^9(p,d)Be^8$ reaction were determined by measuring simultaneously the intensity of protons at four sets of angles. The method is illustrated schematically in Fig. 2. A beam of protons from the Notre Dame electrostatic accelerator was incident on a Be foil. Deuterons emerging from the foil were slowed down in Fe and Al absorber foils and allowed to enter a He^3-filled cell. Protons from the $He^3(d,p)He^4$ reaction ($Q=18.34$ MeV) were detected in four CsI crystals

[10] F. Seiler, S. E. Darden, L. C. McIntyre, and W. G. Weitkamp, Nucl. Phys. **53**, 65 (1964).
[11] A. Galonsky, H. B. Willard, and T. A. Welton, Phys. Rev. Letters **2**, 349 (1959).
[12] L. C. McIntyre, Ph.D. thesis, University of Wisconsin (unpublished). The discrepancy between the sign of the term containing $\langle T_{21}\rangle$ in Eq. (2) and that of the corresponding term in Eq. (5) of Ref. 10 arises from an error in the latter.
[13] L. Brown, H. Christ, and H. Rudin (private communication).
[14] J. L. Yarnell, R. H. Lovberg, and W. R. Stratton, Phys. Rev. **90**, 292 (1953).

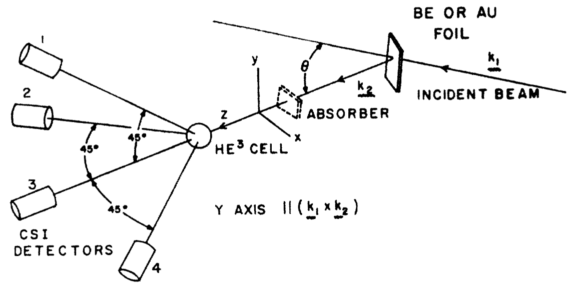

FIG. 2. Schematic representation of the experimental procedure used to measure the tensor polarization of deuterons. Detectors 2, 3, and 4 are in the x–z plane, and detectors 1 and 3 are in the y–z plane

positioned as shown in Fig. 2. Detectors 2, 3, and 4 are in the x-z plane, and detectors 1 and 3 are in the y-z plane. A top view of the scattering chamber, He^3 cell, and CsI detectors is given in Fig. 3. The emission angle at which deuterons are observed can be changed continuously from 0° to 135°. The square entrance aperture for the He^3 cell subtends an angle of 7° at the position of the Be foil. Apertures in front of the CsI crystals are $\frac{3}{4}$ in. in diameter and are a distance of 3 in. from the center of the He^3 cell. The cell itself is essentially identical in design to the cell described in Ref. 10, except that the depth of the cell used for most of the experiment, measured along the direction of the incident deuterons, was considerably less, and the He^3 pressure correspondingly higher. For most of the measurements a He^3 pressure of 120 psi was used.

Sufficient absorber foils were placed between the Be foil and the He^3 cell to ensure that the deuterons entered the cell with an average energy of about 800 keV. In order to obtain this deuteron energy in the He^3 cell, the combined yield in all four proton detectors was measured as a function of proton bombarding energy with appropriate slowing-down foils in front of the He^3 cell. This measured yield curve was then compared with a calculated yield curve obtained from the known He^3 pressure, the reaction cross section and the energy loss of deuterons in He. In this way it was possible to adjust the average energy of deuterons entering the second cell. The estimated uncertainty in this energy is about ±75 keV.

Since the protons from the $He^3(d,p)He^4$ reaction have an energy of almost 15 MeV in the lab system, they can easily traverse the wall of the He^3 cell and the few inches of air to the CsI crystals and still have enough energy to produce pulses substantially larger than anything else entering the crystals. The thickness of the crystals was chosen to be sufficient to stop the protons. Backgrounds were measured by inserting in front of the He^3 cell an aluminum foil thick enough to completely stop the deuterons. Pulses from the CsI detectors were recorded in the four quadrants of a 256-channel analyzer. A typical set of pulse-height spectra is shown in Fig. 4. The only significant backgrounds occurred in detector 2, and these arose mainly from the somewhat poorer pulse-height and resolution characteristics of this particular crystal.

Effects arising from differences in efficiencies and in solid angles subtended by the different detectors were eliminated by measuring the counting rates in the four detectors when the Be foil was replaced by a gold foil and deuterons elastically scattered from this foil were allowed to enter the He^3 cell. For these measurements, a deuteron bombarding energy of 3 MeV, and a laboratory scattering angle of 50° were used. At this energy and angle only Rutherford scattering is effective and the deuterons entering the He^3 cell are unpolarized. The relative counting rates observed in the four detectors under these conditions can thus be used to normalize the data, eliminating the effect of any differences in solid angle or efficiency among the detectors. This procedure was checked by also measuring the relative counting rates with the scattering chamber in the zero-degree position. The direct deuteron beam from the accelerator was allowed to enter the He^3 cell and counting rates in the four detectors were measured. Relative counting rates observed in this way were identical, within statistics (1%), to those obtained using scattered deuterons.

Measurements for a given proton bombarding energy and deuteron emission angle were generally preceded and followed by a normalization measurement using the gold foil. Background counting rates were taken at appropriate intervals throughout the series of measure-

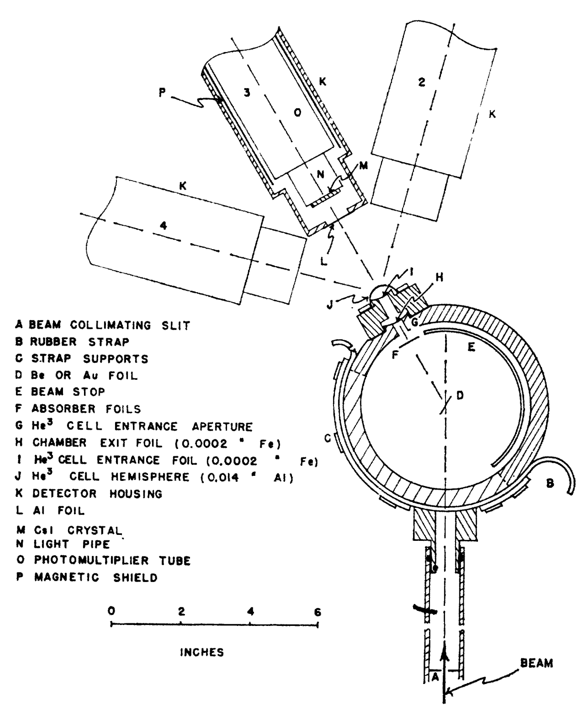

FIG. 3. Top view of the scattering chamber, He^3 cell, and CsI detectors. Detector 1 has been omitted for clarity.

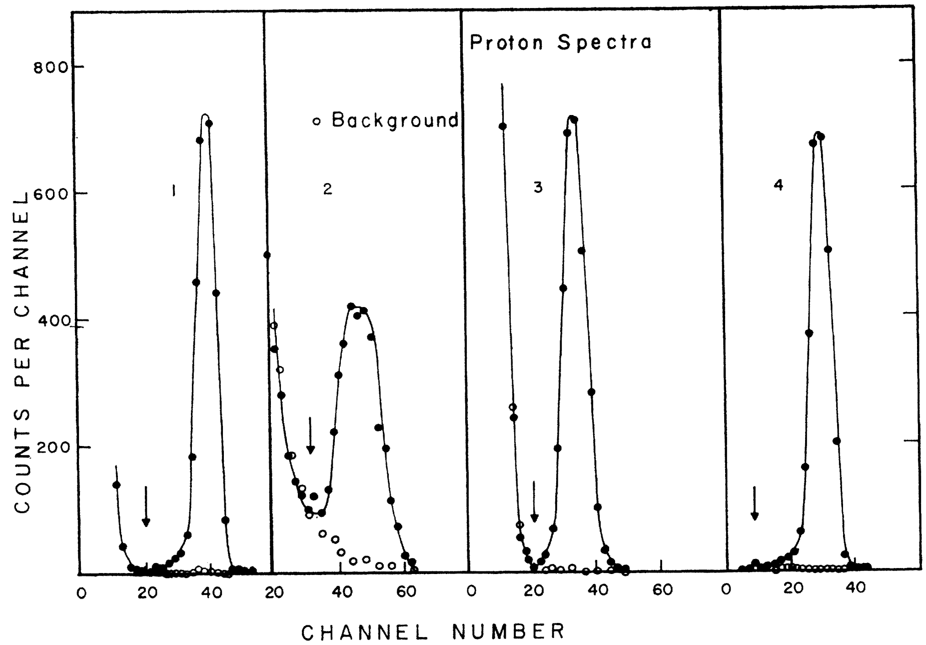

FIG. 4. A typical set of pulse-height spectra from the CsI detectors. The open circles give the background spectra.

ments for a given energy and angle. Since only the relative counting rates in the four detectors are required to determine the $\langle T_{2q}\rangle$, variations in the incident beam current during individual runs were of no consequence.

In order to obtain reasonable counting rates, fairly thick Be foils were used. Most of the data were taken with a 1-mil Be foil, although some of the measurements were repeated using a $\frac{1}{2}$-mil foil. Considerable energy spread in the outgoing deuterons may be introduced by the use of thick foils because the deuteron energy loss in the foil exceeds that of the protons. This energy spread was minimized in most cases by proper choice of the angle between the normal to the plane of the Be foil and the direction of the incident proton beam. The resulting average thickness of the Be foil to the incident protons varied between 450 and 600 keV.

Since both the differential cross-section for the $Be^9(p,d)Be^8$ reaction and the energy of the emitted deuterons vary with angle, the effective center of the He^3 cell will be displaced somewhat from the geometric center. For the geometry used in this experiment, this effect introduces a slight left-right asymmetry in the emitted protons approximately equivalent in the worst case to that resulting from a value of $\langle T_{21}\rangle$ equal to -0.02. No correction to the data was made for this effect, however, since a left-right asymmetry of the same order is introduced by the variation with angle of the Rutherford scattering in the normalization data taken with deuterons scattered from gold. The correctness of the estimated small magnitude of this effect was attested to by the close agreement between relative counting rates observed with deuterons scattered from gold at an angle of 50° and those observed when the deuteron beam was allowed to enter the He^3 cell directly. An additional indication that this geometrical effect did not measurably affect the results for $\langle T_{21}\rangle$ was provided by repeating the measurements at a proton energy of 2.5 MeV and an angle of 30°, using additional collimating apertures to reduce the angular divergence of the deuterons entering the He^3 cell. Although the angular divergence was reduced below its normal value by a factor of three for this measurement, the results were in agreement with those obtained using the larger aperture.

III. RESULTS

The normalized measured counting rates in the four detectors were equated to expressions obtained by integrating Eq. (2) over the solid angles subtended by the detectors and the resulting four equations were solved for the $\langle T_{2q}\rangle$. Results obtained for an average proton energy of 2.5 MeV are shown in Fig. 5, and those for an average proton energy of 3.7 MeV in Fig. 6. The $\langle T_{2q}\rangle$ have been plotted as a function of c.m. reaction angle and refer to the coordinate system shown in Fig. 2, where the angle θ is measured in the c.m. system. A value of β of 0.85 was used in Eq. (2).

Only statistical uncertainties are indicated in Figs. 5 and 6. The larger statistical uncertainties in $\langle T_{20}\rangle$ result from the choice of angles at which the detectors were placed. There are a number of uncertainties affecting the measured polarizations in addition to those arising from counting statistics. Besides the small geometrical uncertainty in $\langle T_{21}\rangle$ discussed in Sec. II, there is an uncertainty in $\langle T_{20}\rangle$ which occurs because the position of the effective center of the volume in the He^3 cell from which the protons originate depends on the average energy of the deuterons entering the cell. If this average energy for the deuterons from the $Be^9(p,d)Be^8$ reaction differs significantly from that of the deuterons elastically scattered from gold, an error will be introduced into the measured value of $\langle T_{20}\rangle$. The uncertainty introduced by this effect is estimated to be of the same order as or less than the statistical uncertainty in most cases. The fact that $\langle T_{21}\rangle$ and $\langle T_{22}\rangle$ systematically vanish at 0°, as they must, strongly suggests that no other geometrical uncertainties are significantly affecting the data.

A systematic uncertainty in the magnitude of the results is introduced by the uncertainty in the value of β. This uncertainty in β is difficult to estimate, but from the work of Brown *et al.*[13] would appear to be about 5%.

Beckner *et al.*[15] have observed the deuteron spectrum obtained when thin Be foils are bombarded with 5.2-MeV deuterons. Their results indicate the presence of a small contribution to the deuteron spectrum, in the energy region of the ground-state group, from the sequential decay process $B^{10*}\rightarrow Li^{6*}+\alpha$; $Li^{6*}\rightarrow \alpha+d$. From the results of these authors it can be estimated that the deuterons entering the He^3 cell in the present experiment contain a contribution from these sequential decay deuterons of the order of 5% or less.

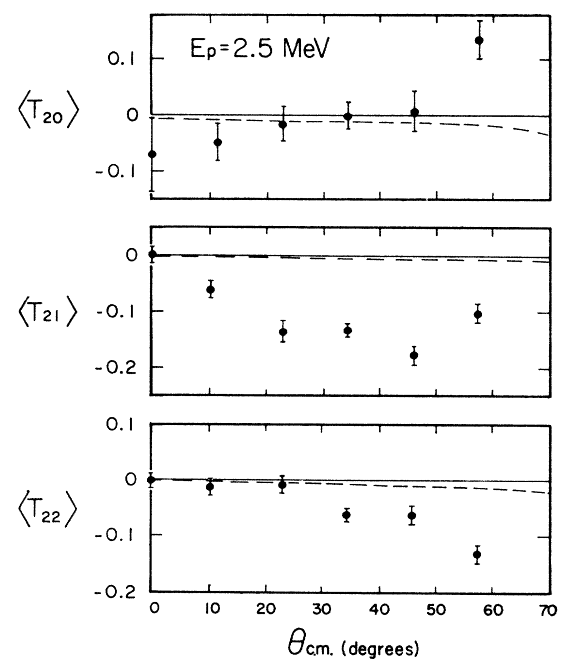

FIG. 5. Measured tensor polarizations of the deuterons from the $Be^9(p,d)Be^8$ reaction for an average proton bombarding energy of 2.5 MeV. The dashed curves are the results of the DWBA calculation discussed in the text.

[15] E. H. Beckner, C. M. Jones, and G. C. Phillips, Phys. Rev. **123**, 255 (1961).

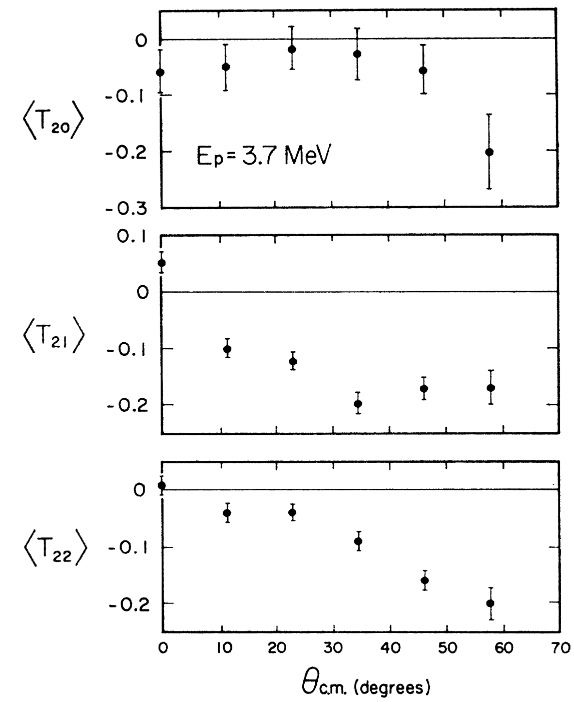

FIG. 6. Measured tensor polarizations of the deuterons from the $Be^9(p,d)Be^8$ reaction for an average proton bombarding energy of 3.7 MeV.

IV. DISCUSSION

It is apparent from Figs. 5 and 6 that non-negligible tensor polarization is produced in the deuterons from the $Be^9(p,d)Be^8$ reaction. The similarity of the results at the two bombarding energies used is not surprising, in view of the similarity in the cross-section data at these two energies, and suggests that no significant information is being lost because of the relatively thick targets employed in the measurements. The largest differences between the results at the two energies occur for a c.m. angle of 58°. This is also not surprising, since this angle is almost off the forward peak in the cross-section and compound nucleus effects may be expected to become relatively more important at larger angles.

Also shown in Fig. 5 are some preliminary results[16] of DWBA calculations of the tensor polarization expected when the optical potentials for the proton and the deuteron include a spin-orbit term of the form

$$V_s\left(\frac{h}{m_\pi c}\right)^2\frac{1}{r}\frac{d}{dr}\left(\frac{1}{e^x+1}\right)\mathbf{l}\cdot\boldsymbol{\sigma},\quad \text{where}\quad x=\left(\frac{r-r_0A^{1/3}}{a}\right).$$

For these calculations, optical potentials giving reasonably good fits to elastic scattering data for Be^9+p at 9 MeV, and Be^9+d at 10 MeV, were used. The values of the parameters V_s, r_0, and a in the proton spin-orbit potential were 7 MeV, 1.50 F, and 0.50 F, respectively,

[16] G. R. Satchler (private communication).

while in the deuteron potential these parameters were taken to be 6 MeV, 1.0 F, and 1.0 F, respectively. A surface-absorption term was used in the central potential for both protons and deuterons. In these calculations it was assumed that the neutron is picked up from a $p_{3/2}$ state in Be^9. The cross section calculated using these parameters is shown in Fig. 1.

Although the calculated $\langle T_{2q}\rangle$ generally agree with the measurements in sign, they seem to be consistently smaller than the measured values by at least an order of magnitude. Varying the depth of the central potential and using volume absorption instead of surface absorption for the deuteron does not improve the agreement significantly, nor does the use of a complex spin-orbit term. The effect of increasing V_s in the deuteron potential from 6 to 8 MeV is to increase the magnitude of $\langle T_{22}\rangle$ by about a factor of 2 and to increase $\langle T_{21}\rangle$ somewhat less, but the predicted $\langle T_{20}\rangle$ then become positive for angles less than about 60°.

It remains to be seen whether the small values of the $\langle T_{2q}\rangle$ predicted by the DWBA calculations result from the failure to include additional spin-dependent interactions, such as the tensor interaction, in the calculations. Another possible shortcoming of the calculations may be the assumption that Be^9 is well described by a $p_{3/2}$ neutron moving in the field of a spherically symmetric Be^8 core. The inclusion of deformation effects in the Be^9 nucleus might alter the predictions of the DWBA appreciably.

V. ACKNOWLEDGMENTS

The authors are indebted to Dr. G. R. Satchler for performing the DWBA calculations referred to in the text. In addition, we would like to express our gratitude to Dr. Louis Brown, Dr. Hans Christ and Dr. Hermann Rudin for permission to quote some of their results on the $He^3(d,p)He^4$ reaction. Thanks are also due to Dr. L. McIntyre for permission to use his results on the cross section for the $He^3(d,p)He^4$ reaction. The work of Bro. Cosmas, C.S.C. and his colleagues in constructing the scattering chamber is likewise gratefully acknowledged. Finally, the authors would like to express their gratitude to James Hevezi and George Spalek for many hours of assistance in collecting the data.

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Regeneration of K_1^0 Mesons and the K_1^0-K_2^0 Mass Difference*

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We have studied the regeneration of K_1^0 mesons using a beam of K_2^0 mesons produced at the Brookhaven AGS. The K_1^0 mesons were detected with a pair of magnet–spark-chamber spectrometers that momentum-analyzed the two decay pions. A test of the coherence of the transmission regeneration is made by comparing the yields from half- and full-density copper regenerators. The K_1^0-K_2^0 mass difference was measured with a regenerator consisting of two pieces of copper separated by a variable air gap. This method is independent of all nuclear scattering parameters and yields a mass difference of 0.50±0.10 in units of $\hbar/\tau_1$ (where τ_1 is the K_1^0 mean life). Data taken with single copper regenerators of various thicknesses yield mass differences consistent with this measurement. Mass differences larger than 1.0 are strongly rejected by our data. The forward regeneration cross sections for C, Cu, Fe, and W were measured and found to agree with optical-model calculations. Regeneration in liquid hydrogen was also investigated and the results compared with theoretical predictions.

I. INTRODUCTION

THE striking prediction[1] that the passage of a parallel beam of K_2^0 mesons through a slab of material generates a parallel beam of K_1^0 mesons was confirmed by R. H. Good *et al.*[2] The regeneration theory[3,4] predicts a dependence of the K_1^0 intensity on the mass difference. The mass difference has been measured via the regeneration phenomenon by several authors.[2,5] The present experiment was performed to study the coherent regeneration mechanism in detail and to make a precise measurement of the K_1^0-K_2^0 mass difference.

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[1] A. Pais and O. Piccioni, Phys. Rev. **100**, 1487 (1955).

[2] R. H. Good, R. P. Matsen, F. Muller, O. Piccioni, W. M. Powell, H. S. White, W. B. Fowler, and R. W. Birge, Phys. Rev. **124**, 1223 (1961).

[3] M. L. Good, Phys. Rev. **106**, 591 (1957).

[4] K. M. Case, Phys. Rev. **103**, 1449 (1956).

[5] T. Fujii, J. V. Jovanovich, F. Turkot, and G. T. Zorn, Phys. Rev. Letters **13**, 253, 324 (1964).