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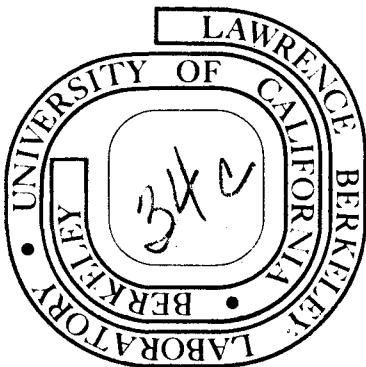
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AT 45.4 MeV AND THE NUCLEON  
NUCLEON INTERACTION

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Prepared for the U. S. Atomic Energy Commission  
under Contract W-7405-ENG-48



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THE VECTOR ANALYZING POWER IN d-p SCATTERING AT 45.4 MeV AND THE NUCLEON  
NUCLEON INTERACTION\*

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Abstract:

The deuteron vector analyzing power in deuteron-proton elastic scattering has been measured at  $E_d = 45.4$  MeV. Our results, when compared with recent three-body calculations, suggest the possibility of deducing information on the n-p phase shift parameters which has not been available from n-p scattering itself.

- - -

During the past few years, three-body calculations<sup>1-5</sup> have achieved notable success in fitting measured polarization observables<sup>6-13</sup> in elastic nucleon-deuteron scattering. These calculations, which use the Faddeev equations with separable nucleon-nucleon potentials, have been made with more and more complicated N-N interactions. The simple S-wave force had been sufficient to give agreement only with the differential cross-section data.<sup>14,15</sup> The increasingly accurate and extensive polarization data, including nucleon and deuteron vector analyzing powers and deuteron tensor analyzing powers,<sup>16</sup> have played a significant role in this theoretical refinement. It now seems possible to derive from such data, via the three-body calculations, information on the N-N interaction which, as yet, has not been available from N-N scattering experiments. The most recent calculations of Doleschall<sup>5</sup> show

a surprisingly strong dependence of the nucleon and deuteron vector polarizations on variations of the input  ${}^3S_1$ - ${}^3D_1$  N-N tensor interaction. We report here measurements<sup>17</sup> of the deuteron vector analyzing power,  $iT_{11}$ , in d-p elastic scattering at  $E_d = 45.4$  MeV, which can be compared directly with the calculated vector polarization at the equivalent nucleon energy  $E_N = 22.7$  MeV.

Although it has been known<sup>1-3,12</sup> that the vector polarizations in N-d scattering are essentially due to the N-N P-wave interactions, there have been conflicting conclusions concerning the contribution to these polarizations from the tensor force. Pieper<sup>4</sup> reported only slight changes with the addition of the tensor force, and he suggested<sup>18</sup> that changes in the  ${}^3S_1$ - ${}^3D_1$  potential would have little effect on the nucleon polarizations. This conjecture was based on Sloan and Aarons<sup>1</sup> result, which demonstrated that none of the N-d polarizations were very sensitive to changes in the  ${}^3S_1$ - ${}^3D_1$  potential. However, that calculation did not include the P-wave interactions, so the calculated vector polarizations were unrealistically small. Doleschall's first calculation<sup>3</sup> showed a substantial change in the vector polarizations with the addition of the tensor force to the S and P-wave interactions, and his most recent calculation<sup>5</sup> shows that the vector polarizations are quite sensitive to the details of the  ${}^3S_1$ - ${}^3D_1$  potential. It is just this sensitivity that offers the promise of providing information on the  ${}^3S_1$ - ${}^3D_1$  n-p mixing parameter  $\epsilon_1$ , and the  ${}^1P_1$  phase shift, which are strongly correlated and poorly determined from phase shift analyses of n-p scattering data below 80 MeV.<sup>19</sup> Although Doleschall does not address this question, it seems clear that correlated variations of  $\epsilon_1$  and the  ${}^1P_1$  phase shift, in a search for improved fits to the vector polarization data, could

result in a better determination of these parameters than has been possible from n-p scattering data.

The polarized deuteron beam from the Berkeley 88-in. cyclotron, passed through a hydrogen gas target in a 36" diameter scattering chamber. The 7.5-cm-diameter gas cell with a 5- $\mu$ m Havar foil window was operated at pressures of 11.55 and 15.02 psi. The vector polarization of the beam was 83% of the maximum possible value  $P_y = \frac{2}{\sqrt{3}}$   $it_{11} = 2/3$  with zero tensor components. Left-right asymmetry data were taken simultaneously at angles separated by  $20^\circ$ , using pairs of  $\Delta E$ -E silicon detector telescopes. This allowed simultaneous detection of forward scattered deuterons and recoil protons from backward scattered deuterons. In order to eliminate instrumental asymmetries, alternate runs were taken with the spin vector of the beam oriented up and down with respect to the scattering plane. The angular resolution, defined by tantalum collimators, was  $0.71^\circ$  and  $1.31^\circ$  (FWHM) for the forward and backward telescopes, respectively. Two monitor counters were placed left and right of the beam axis at a scattering angle of  $\theta \simeq 23^\circ$  and azimuthal angles  $\phi \simeq 70^\circ$  and  $110^\circ$ . This enabled a relative cross section measurement to be made which was used in a finite geometry correction to the vector analyzing power. A helium gas cell along with a pair of  $\Delta E$ -E counter telescopes at equal left and right scattering angles were positioned in a smaller scattering chamber downstream from the main scattering chamber and provided a continuous monitoring of the beam polarization. The analyzing power of the  $d$ - $^4\text{He}$  at this energy had been previously measured in detail.<sup>20</sup>

Our experimental results are shown in Fig. 1, where the relative errors include the statistical error and a contribution of  $\pm 0.004$  which

was determined from measured asymmetries with the beam polarization set to zero. In addition, there is a  $\pm 3\%$  normalization uncertainty from that of the  $d$ - $^4\text{He}$  analyzing power. Also shown in Fig. 1 are Doleschall's calculated results.<sup>5</sup> In this calculation he used an improved set of P-wave potentials which provide much better agreement with the two-nucleon P-wave phase shifts<sup>19</sup> for the lower energies which contribute in the three-nucleon calculation. Additionally, rank-2 tensor interactions were constructed in an attempt to simultaneously reproduce the  $^3S_1$ ,  $^3D_1$  phase shifts, the mixing parameter  $\epsilon_1$ , and the deuteron properties. It was not possible to find a single rank-2 tensor force which satisfied all of these criteria, so two such sets were used. One, the T4D force, reproduced the low energy ( $\leq 100$  MeV)  $^3D_1$  phase shifts but gave larger values of  $\epsilon_1$  than have been deduced from n-p scattering.<sup>21</sup> The other, the T4M force, reproduced the low energy  $\epsilon$  behavior but not that of the  $^3D_1$  phase shifts. As shown in Fig. 1, the T4M force calculation is in good agreement with our data backward of  $\theta_c \simeq 80^\circ$ , but the agreement deteriorates at the forward angles. Even though the calculations are for n-d scattering they can be compared with our data since charge symmetry of the nuclear interaction provides equality of the n-d and p-d polarizations in the absence of Coulomb effects. Such effects have been demonstrated to be small near  $E_N = 22$  MeV, in that the nucleon analyzing power in n-d<sup>22</sup> and p-d<sup>10</sup> scattering are equal within the experimental error. In a further effort to improve the agreement between experiment and theory for the proton analyzing power data,<sup>10</sup> Doleschall also included a  $^3D_2$  interaction. Computational limitations precluded the addition of a complete set of D-wave interactions. The result of that calculation with the T4M interaction, the T4M +  $^3D_2$

result, is also shown in Fig. 1. Some improvement toward agreement is seen at the forward angles at the expense of a slightly poorer fit in the region  $\theta_c = 85^\circ$  to  $115^\circ$ . A very similar comparison between experiment and theory was found for the proton analyzing power data.<sup>5</sup>

The three-nucleon calculations represent major progress in predicting the polarization observables in N-d elastic scattering below 50 MeV. Small discrepancies remain with the vector polarizations in the forward angle region, which is just the region of greatest sensitivity to details of the  $^3S_1$ - $^3D_1$  tensor interaction. Clearly, it would be most useful to do the calculation with a tensor force which simultaneously reproduces the N-N  $^3D_1$  phase shift and the mixing parameter  $\epsilon_1$ , for example, the rank-4 potential recently constructed by Pieper.<sup>23</sup> It should then be possible to vary  $\epsilon_1$  and the  $^1P_1$  phase shift, in the correlated manner required by the n-p scattering data,<sup>19</sup> in a search for improved fits to the p-d proton and deuteron vector polarization data. It is quite possible that this procedure could provide a better determination of the low energy values of these two parameters than is possible via the suggested<sup>19</sup> more difficult measurements of the  $\bar{\sigma}(180^\circ)/\bar{\sigma}(90^\circ)$  ratio in n-p scattering to an accuracy of better than 2%.

We are grateful to R. M. Larimer for her assistance during the experiment, and to P. Doleschall for sending us numerical results of his calculations. We also benefited from a discussion with D. P. Saylor.

FOOTNOTES AND REFERENCES

\* Work performed under the auspices of the U. S. Atomic Energy Commission.

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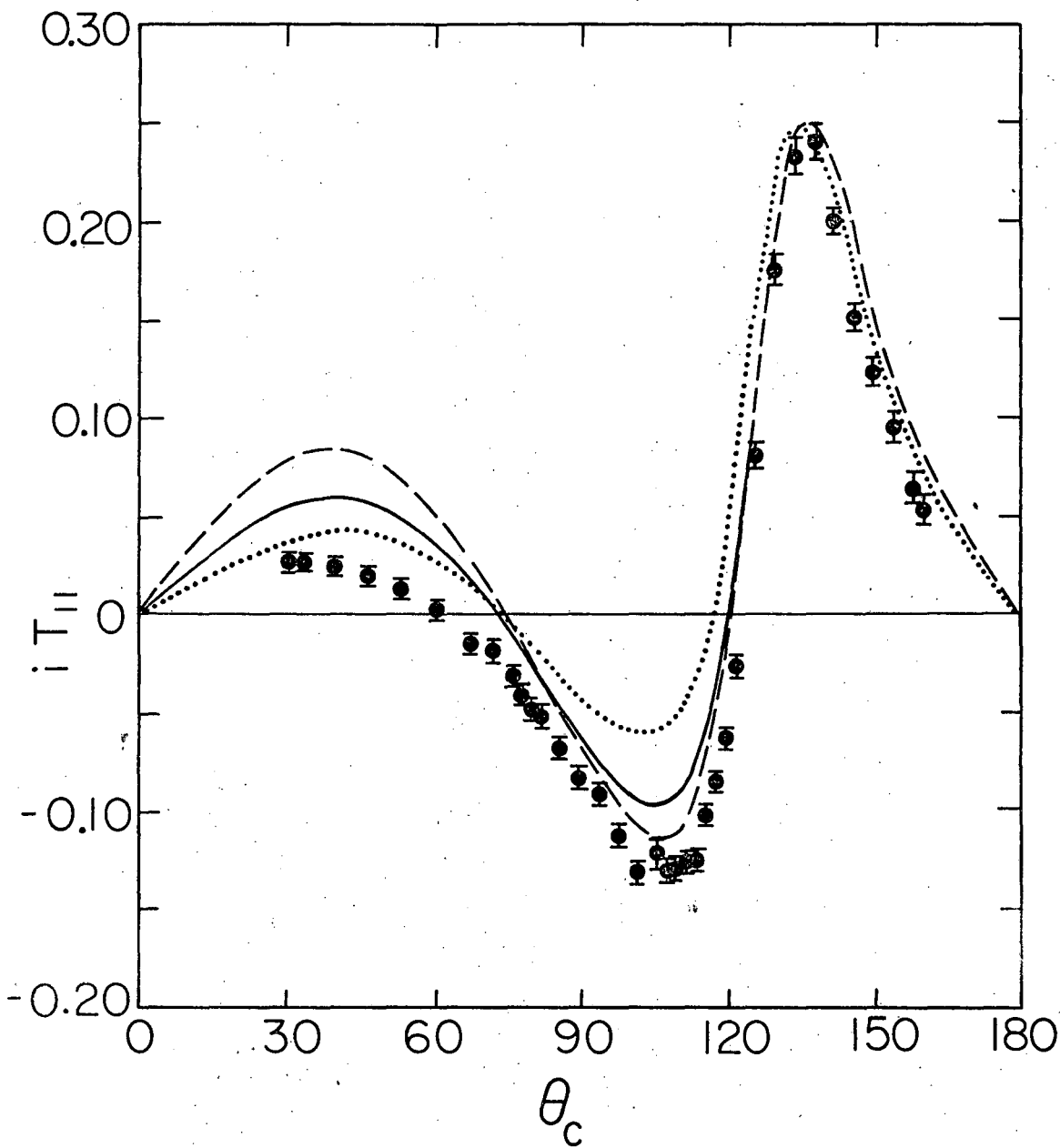
1. J. C. Aarons and I. H. Sloan, Nucl. Phys. A182, 369 (1972); I. H. Sloan and J. C. Aarons, *ibid.* A198, 321 (1972).
2. S. C. Pieper, Nucl. Phys. A193, 529 (1972).
3. P. Doleschall, Phys. Lett. 40B, 443 (1972); Nucl. Phys. A201, 264 (1973).
4. S. C. Pieper, Phys. Rev. C 6, 1157 (1972).
5. P. Doleschall, Nucl. Phys. A220, 491 (1974).
6. H. E. Conzett, G. Igo, and W. J. Knox, Phys. Rev. Lett. 12, 222 (1964).
7. H. E. Conzett, H. S. Goldberg, E. Shield, R. J. Slobodrian and S. Yamabe, Phys. Lett. 11, 68 (1964).
8. T. B. Clegg and W. Haeberli, Nucl. Phys. A90, 593 (1967).
9. S. N. Bunker, J. M. Cameron, R. F. Carlson, J. R. Richardson, P. Tomas, W. T. H. van Oers, and J. W. Verba, Nucl. Phys. A113, 461 (1968).
10. J. C. Faivre, D. Garreta, J. Jungerman, A. Papineau, J. Sura, and A. Tarrats, Nucl. Phys. A124, 169 (1969).
11. R. E. White, W. Gruebler, V. König, R. Risler, A. Ruch, P. A. Schmelzbach, and P. Marmier, Nucl. Phys. A180, 593 (1972).
12. J. S. C. McKee, H. E. Conzett, R. M. Larimer, and Ch. Leemann, Phys. Rev. Lett. 29, 1613 (1972).
13. A. Fiore, J. Arvieux, Nguyen Van Sen, G. Perrin, F. Merchez, J. C. Gondrand, C. Perrin, J. L. Durand, and R. Darves-Blanc, Phys. Rev. C 8, 2019 (1973).



14. R. Aaron, R. D. Amado, and Y. Y. Yam, Phys. Rev. 140, B1291 (1965).
15. I. H. Sloan, Phys. Rev. 185, 1361 (1969); Nucl. Phys. A168, 211 (1971).
16. We use the nomenclature and notation of the Madison Convention, Polarization Phenomena in Nuclear Reactions, edited by H. H. Barschall and W. Haeberli (Univ. of Wisconsin Press, Madison, 1971), p. XXV.
17. F. N. Rad, J. Birchall, H. E. Conzett, S. Chintalapudi, R. M. Larimer, and R. Roy, Bull. Amer. Phys. Soc. 19, 476 (1974).
18. S. C. Pieper, Phys. Rev. C 8, 1702 (1973).
19. M. H. MacGregor, R. A. Arndt, and R. M. Wright, Phys. Rev. 182, 1714 (1969).
20. Ch. Leeman, H. E. Conzett, W. Dahme, J. A. Macdonald, and J. P. Meulders, Bull. Amer. Phys. Soc. 17, 562 (1972), and to be published.
21. The constrained solution values of  $\epsilon_1$  and  $\delta(^1P_1)$  as given in Table VII, Ref. 19, were used.
22. J. J. Malanify, J. E. Simmons, R. B. Perkins, and R. L. Walters, Phys. Rev. 146, 532 (1966); C. L. Morris, R. Rotter, W. Dean, and S. T. Thornton, Phys. Rev. C 9, 1687 (1974).
23. S. C. Pieper, Phys. Rev. C 9, 883 (1974).

## FIGURE CAPTION

Fig. 1. The deuteron vector and analyzing power,  $iT_{11}(\theta)$ , in d-p elastic scattering at  $E_d = 45.4$  MeV. The curves are calculated results from Ref. 5 with different N-N interactions. Dotted line, set C (S and P-waves) + T4D tensor potential; dashed line, set C + T4M; solid line, set C + T4M +  ${}^3D_2$ .



XBL744-2770A

Fig. 1

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