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VECTOR-TO-VECTOR POLARIZATION TRANSFER IN DEUTERON-PROTON ELASTIC SCATTERING*

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Abstract:

An angular distribution of the polarization transfer coefficient $K_y^{y'}(\theta)$ in d-p elastic scattering has been measured at E_d = 45.4 MeV. Our results are in very good agreement with the prediction of a recent three-body calculation.

We report in this letter on the first significant comparison between experimental and theoretically calculated vector-to-vector polarization transfer coefficients in nucleon-deuteron elastic scattering.

Considerable theoretical progress has been made recently in fitting the nucleon analyzing-powers measured in N-d elastic scattering at energies below 50 MeV.[1-3] These three-nucleon calculations, based on the Faddeev equations with separable nucleon-nucleon interactions, have also provided predictions of the deuteron vector and tensor polarizations and, more recently, of polarization transfer coefficients[4] at energies up to E_N = 23 MeV. Subsequent determinations of the deuteron analyzing-powers were in good agreement with the calculations.[5] These studies showed that the P-wave part of the N-N interaction was chiefly responsible for the vector analyzing power, whereas, in addition, the two-body $^3S_1$ - $^3D_1$ tensor force was required in order to provide agreement with the observed tensor analyzing powers.

As a further test of the theoretical predictions, we report on measurements of the polarization of the recoil protons in d-p elastic scattering with incident 45.4 MeV vector polarized deuterons.[6] These $^1H(\vec{d},\vec{p})^2H$ measurements provide determinations of the vector-to-vector polarization transfer coefficient, $K_y^{y'}(\theta)$, defined by the equation[7]

$$p_{y'} = (A_{y'} + \frac{3}{2} p_y K_y^{y'})/(1 + \frac{3}{2} p_y A_y), \tag{1}$$

where p_y is the polarization of the purely vector polarized incident deuteron beam, $p_{y'}$ is the observed polarization of the outgoing (recoil) proton, and A_y and $A_{y'}$ are, respectively, the deuteron vector analyzing power and the proton analyzing power in d-p elastic scattering. The Madison convention[8] is followed in defining the cartesian forms of the polarization and analyzing power, and the y and y' axes are taken along $\vec{k}_d \times \vec{k}_p$. From time-reversal invariance, the same coefficient describes the transfer of vector polarization in the inverse $^2H(\vec{p},\vec{d})^1H$ scattering process at the equivalent proton energy of 22.7 MeV.[7] Thus, our measurements can be compared directly with Pieper's[4] calculated $K_y^{y'}(\theta)$ at that energy.

Previous measurements of vector-to-tensor polarization transfer coefficients in p-d scattering were made at two angles at several energies between 5 and 9 MeV.[9] The values were consistent with zero within a typical error of ± 0.05. Pieper's later three-body calculation[4] gave predicted values of these coefficients to be less than 0.1 for energies below 10 MeV, in essential agreement with the data. Of particular interest was his prediction that the vector-to-vector transfer coefficients differed more substantially from zero. A single measured value of $K_x^{x'}(\theta)$ at 9 MeV[10] was two standard deviations from the calculated value, but it was clear that more data were

required for a realistic comparison with the predictions. His calculation also predicted substantial values of $K_y^{y'}(\theta)$ at $E_p = 22.7$ MeV.

Our experimental arrangement is shown in Fig. 1. The polarized deuteron beam from the Berkeley 88-inch cyclotron passed through a high pressure liquid-nitrogen-cooled hydrogen gas target, positioned in a 36-inch diameter scattering chamber. The entrance and exit windows of the gas target were Havar foils of 25 μm in thickness. The areal density of the gas was 12.8 mg/cm^2 at the operating pressure of 12.4 atm, and the mean energy in the gas was 45.4 MeV. Two silicon polarimeters, described in detail elsewhere,[11] were used to determine the polarization of the scattered protons. They were positioned at equal scattering angles to the left and right of the beam axis. The angular resolution, defined by tantalum collimators, was 0.8° (FWHM). Two monitor counters were placed left and right of the beam axis at a scattering angle of $\theta \simeq 22^\circ$ and azimuthal angles near 70° and 110°. A helium gas target cell and a pair of ΔE-E counter telescopes at equal left and right scattering angles were positioned in a smaller scattering chamber downstream from the main scattering chamber, and this provided continuous monitoring of the beam polarization. The vector polarization of the beam, with zero tensor component, was near 0.81 ± .03 of the maximum possible value $p_y = 2/3$. The analyzing power of d-^{4}He scattering at this energy had been measured previously.[12] For each determination of $K_y^{y'}(\theta)$, data were taken with the spin vector of the beam orientated alternately up and down with respect to the scattering plane. This mode of operation along with the left-right polarimeters provided several internal consistency checks. The relative yield of elastic doubly-scattered protons into the LL detector of the silicon polarimeter is given by:

$$LL^{\pm} = (1 \mp 3/2\ p_y A_y)\ (1 + p_{y'} A_2), \tag{2}$$

where the (+) and (-) superscripts correspond to the incident beam spin orientation of up and down, respectively, and A_2 is the silicon proton analyzing power in the second scattering.[13] Inserting $p_{y'}$ from Eq. (1),

$$LL^{\pm} = 1 \mp 3/2\ p_y A_y + A_2 A_{y'} \pm 3/2\ A_2 p_y\ K_y^{y'} \tag{3}$$

From this and similar expressions for the relative yields $LR^{\pm}$, $RL^{\pm}$, and $RR^{\pm}$ one obtains[14]

$$3/2\ p_y A_2\ K_y^{y'} = \frac{(LL^+ - LL^-) - (LR^+ - LR^-)}{LL^+ + LL^- + LR^+ + LR^-} \tag{4a}$$

$$= \frac{(RR^- - RR^+) - (RL^- - RL^+)}{RR^- + RR^+ + RL^- + RL^+} \tag{4b}$$

$$= \frac{(LL^+ - RR^+) - (LR^+ - RL^+)}{LL^+ + RR^+ + LR^+ + RL^+} \tag{4c}$$

$$= \frac{(RR^- - LL^-) - (RL^- - LR^-)}{RR^- + LL^- + RL^- + LR^-} \tag{4d}$$

First order systematic errors due to instrumental asymmetries and beam misalignments were eliminated by averaging the values of $K_y^{y'}(\theta)$ from Eqs. (4a) and (4b), and similarly from Eqs. (4c) and (4d). The two average values obtained in this way agreed to within ± 0.006 at all angles. The effective proton analyzing power A_2 of the silicon polarimeter was determined with polarized protons elastically scattered from ^{4}He and ^{12}C, for which $K_y^{y'}(\theta) = 1.0$. With p_y known Eq. (4) then results in a value for A_2. Details of the silicon polarimeter and of the calibration procedures and results are reported elsewhere.[11]

Our experimental results are shown in Fig. 2, where the errors indicated are purely statistical. The solid curve is Pieper's calculation, and it is seen that the agreement with experiment is excellent. Since this constitutes the first significant comparison between experimental and calculated polarization-transfer coefficients in N-d elastic scattering, this agreement represents yet another substantial success of the three-body calculations, particularly in view of the fact that there has been no adjustment of the two-body input parameters in order to fit these data.

Despite the excellent agreement between these experimental and predicted values of $K_y^{y'}(\theta)$, it recently has become clear that further calculations are necessary to address unresolved questions in N-d scattering. Pieper compared his perturbative calculation[4] with Doleschall's exact calculation[2] for the same input N-N interactions, and he found that there were significant differences between the two calculations of the nucleon polarization near 23 MeV. In his most recent calculation, Doleschall[3] improved the P-wave and the $^3S_1$ - $^3D_1$ tensor interactions to give better agreement with the N-N phase-shift parameters. This resulted in improved fits to the nucleon and deuteron[15] vector analyzing-power data. An appropriate question, then, is the extent to which such improved N-N interactions would change the calculated values of $K_y^{y'}(\theta)$. As has been suggested,[15,16] an important program now is to specifically examine the sensitivities of the various analyzing-powers and polarization-transfer coefficients to the details of the input two-body interactions.

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FOOTNOTES AND REFERENCES

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

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‡National Research Council of Canada Post Doctoral Fellow.

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13. For the spin-up orientation, the negative sign in the first term of Eq. (2), and correspondingly in the denominator of Eq. (1), results from the fact that the incident deuteron is scattered to the right, so p_y is opposite to $\vec{k}_i \times \vec{k}_f$.

14. Equation (4b) is analagous to an expression for $p_y A_2 D$ which appeared in work of P. Schnabel, Thesis, University of Paris, 1971 (unpublished). There D is the depolarization parameter in proton elastic scattering from nuclei.

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FIGURE CAPTIONS

Fig. 1. Schematic diagram of the experimental arrangement, showing the left and right silicon polarimeters. The detectors labelled L and R are the left and right silicon analyzers, respectively. LL, LR, RL, and RR are the silicon side detectors of the polarimeters.

Fig. 2. The vector-to-vector polarization transfer coefficient, $K_y^{y'}(\theta)$, in d-p elastic scattering at E_d = 45.4 MeV. The solid curve is the calculated result from Ref. 4.

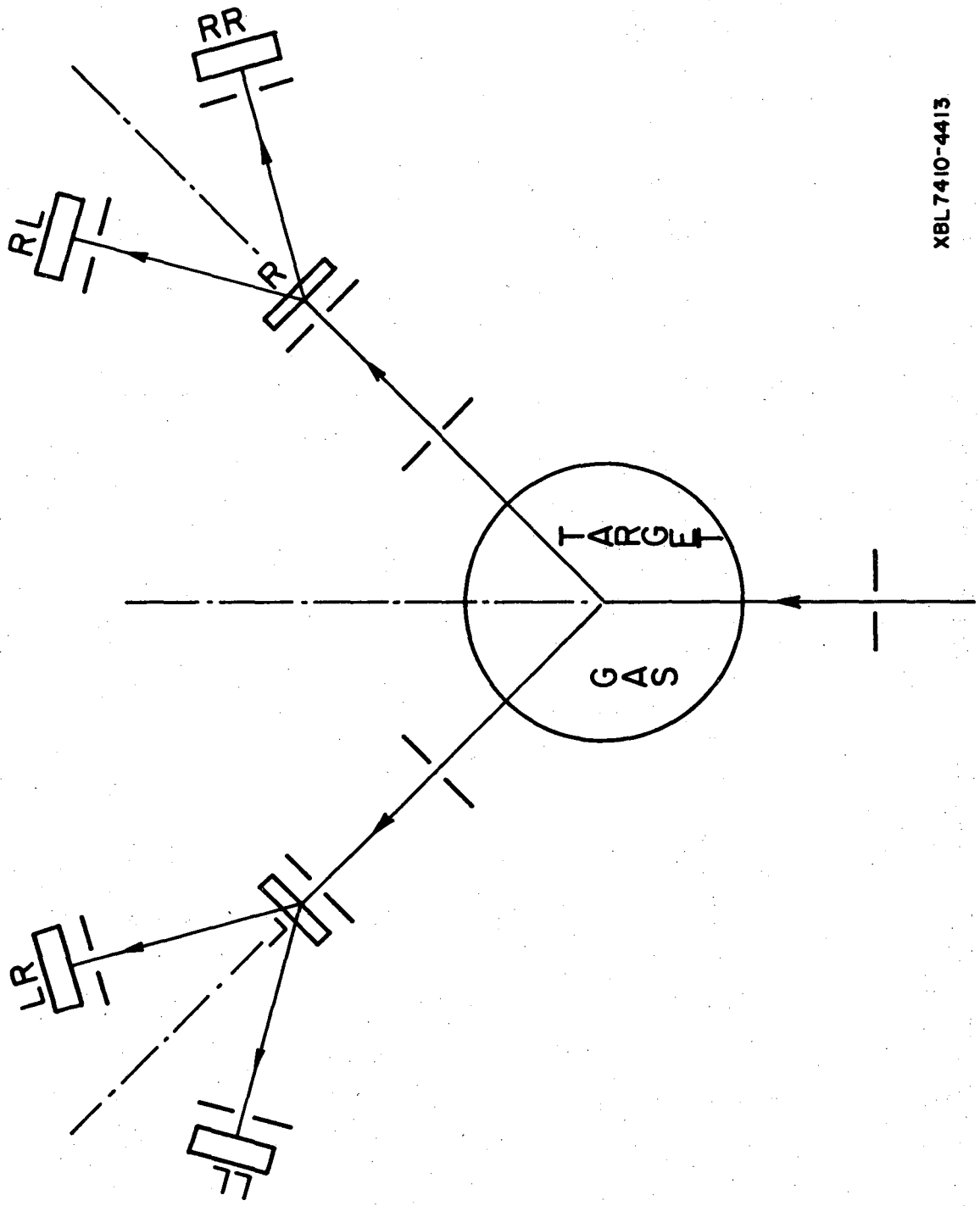

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Fig. 1

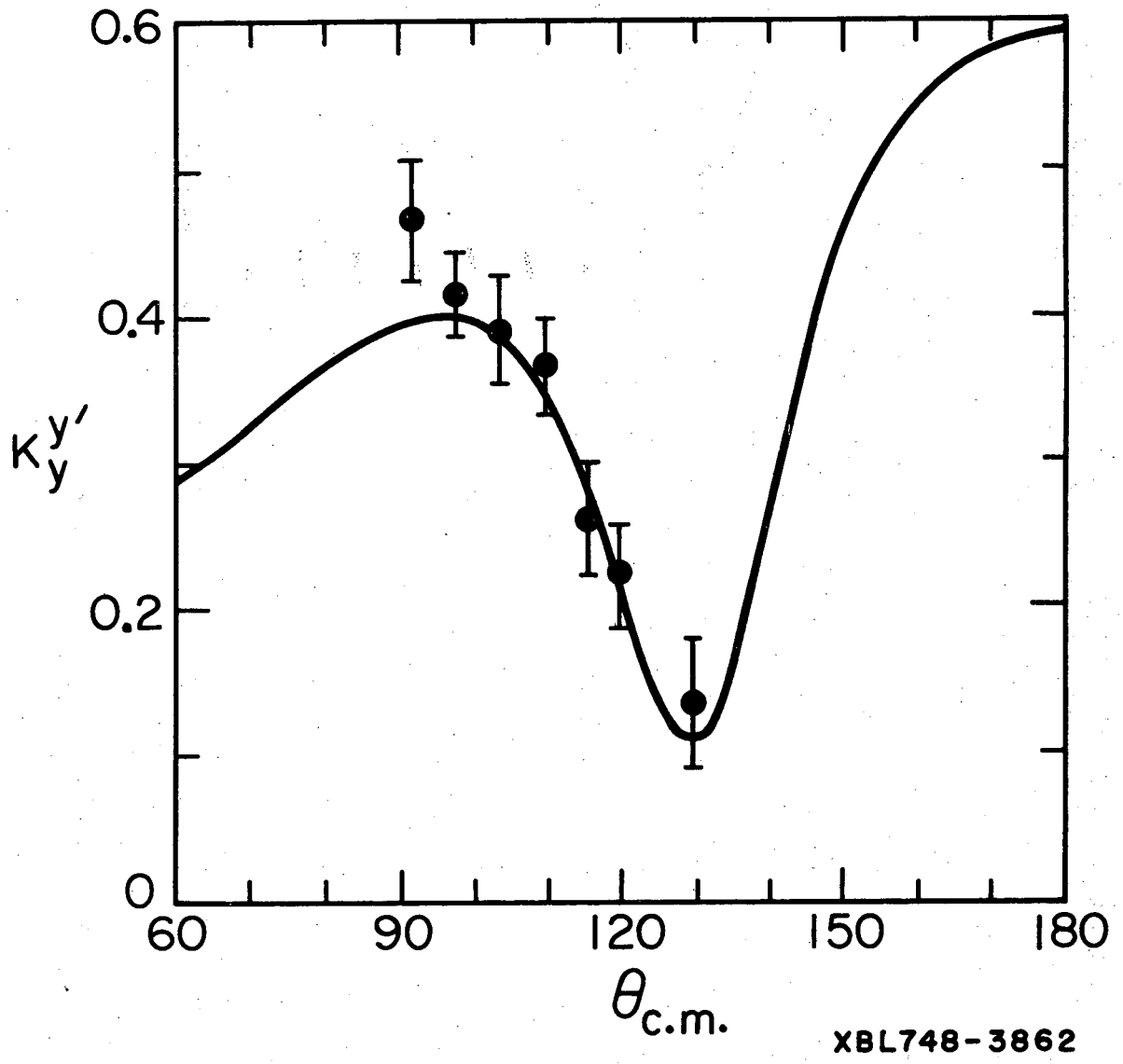

Fig. 2

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