Measurement of the Polarization of Photoneutrons from Deuterium*

WALTER JOHN AND FREDERICK V. MARTIN†
Lawrence Radiation Laboratory, University of California, Livermore, California

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Theoretical studies have predicted that the neutrons from the reaction $D(\gamma,n)H$ are polarized. At low gamma-ray energies, the polarization results from an interference between the electric and magnetic dipole transitions. We have measured the polarization of the photoneutrons produced from deuterium by the 2.75-Mev gamma rays of Na^{24}. The photoneutrons were scattered from magnesium and the polarization determined from the left-right asymmetry using recent experimental results of Elwyn, Lane, and Langsdorf for the polarization-analyzing ability of magnesium. For gamma ray-neutron angles (center-of-mass) of 49.6°, 71.8°, 93.6°, 114.8°, and 135.7°, the neutron polarizations are found to be -0.34 ± 0.05, -0.23 ± 0.06, -0.22 ± 0.06, -0.29 ± 0.05, and -0.24 ± 0.06, respectively, where positive polarization is taken to be in the direction of $\mathbf{k}_\gamma\times\mathbf{k}_n$. The results are in agreement with a calculation by Kramer in the effective-range approximation, assuming only dipole transitions and no noncentral forces.

IT has been pointed out by Rosentsveig[1] and independently by Czyż and Sawicki[2] that the neutrons from the reaction $D(\gamma,n)H$ should be polarized. At low gamma-ray energies, the polarization results from an interference between the electric dipole transition and the spin-flipping magnetic dipole transition. Theoretical studies of the polarization have been published by several authors.[3–9] We present here the first measurements which can be compared to these theories.[10]

We have used the 2.753-Mev gamma rays from a Na^{24} source to disintegrate deuterium. The photoneutron polarization was determined from the left-right asymmetry in the scattering from magnesium. The photoneutron energy in the lab system is given[11] in terms of the lab angle by $E_n(\text{kev})=262+33\cos\theta$. Mg^{24} has a neutron scattering resonance at 260 kev[12] with a width of 75 kev, assigned $J^\pi=\frac{1}{2}^-$. Recently, Elwyn *et al.*[13,14] using polarized neutrons from the $Li(p,n)$ reaction, have found that the polarization-analyzing ability (P_2) for ordinary magnesium is quite high in the vicinity of the 260-kev resonance.

A Na^{24} source was activated in the core of the Livermore pool-type reactor to an approximate activity of one kilocurie and then transferred to the experimental setup shown in Fig. 1. The gamma source consisted of a 3.2-cm diam NaF cylinder inside a 3.2-mm-thick Al can. For the deuterium target, a cylindrical shell, 9.7 cm outside diam and 1.52 mm thick, was molded from deuterated polyethylene. The Mg scatterer consisted of two 3.18-mm-thick plates at right angles. Counting rates were typically 1000 counts/min with scatterer, and 600 counts/min without scatterer. After correcting for decay of the Na^{24}, the net count on the left was divided by the net count on the right to obtain the left-right ratio. In order to investigate the counting rate due to neutrons which scattered from the inner walls of the lead shielding before emerging from the collimator, we displaced the CD_2 20.2 cm from the beam line so that no neutrons would emerge from the collimator directly. The net counting rate was again determined and subtracted from the previous counts as a background. This subtraction raised the left-right ratio at 94°, 115°, and 136° by 0.03, at 72° by 0.06, and at 50° by 0.08. The resulting ratios are listed in Table I under "Measured left-right ratio for Mg." In addition, the left-right ratio was

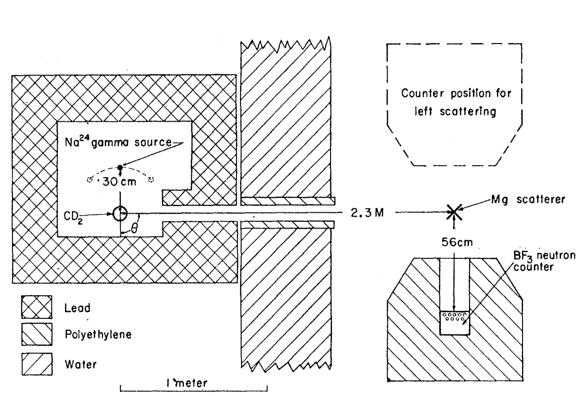

FIG. 1. Plan view of the experimental arrangement. The height of the Na, CD_2, collimator, and Mg is 15.2 cm, the neutron counter is 41 cm in height.

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† Lt. Cmdr., USN, on assignment from U. S. Naval Postgraduate School, Monterey, California.
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TABLE I. Left-right ratios and calculated photoneutron polarization. The polarizations are taken positive in the direction of $\mathbf{k}_i \times \mathbf{k}_0/|k_i \times k_0|$, where $\mathbf{k}_i/k_i$ is the direction of the incident and $\mathbf{k}_0/k_0$ the direction of the outgoing particles. (The errors quoted for P_2 are statistical only. The errors given for P_1 include the statistics of the left-right ratio, the statistics of the CD_2 thickness correction, and the error in P_2.)

$\theta_{c.m.}$ (deg)	Neutron energy lab (kev)	Measured left-right ratio for carbon	Measured left-right ratio for Mg	Corrected left-right ratio for Mg	P_2 for Mg[a]	Photoneutron polarization P_1
49.6	284.5	1.011±0.020	1.324±0.025	1.547	−0.66±0.05	−0.34±0.05
71.8	274.0	0.975±0.017	1.348±0.027	1.390	−0.73±0.05	−0.23±0.06
93.6	262.0	1.005±0.024	1.323±0.023	1.394	−0.79±0.07	−0.22±0.06
114.8	250.0	0.955±0.022	1.373±0.031	1.635	−0.85±0.07	−0.29±0.05
135.7	239.5	1.036±0.025	1.370±0.037	1.526	−0.89±0.08	−0.24±0.06

[a] See reference 14.

measured for a carbon scatterer as a check against false asymmetries. Carbon has been found to have essentially no polarization-analyzing ability at these energies.[15]

The measured left-right ratio for Mg scatterer was corrected for several effects which produce an unpolarized neutron background. Compton scattering of the gamma rays in the Na source is estimated to reduce the left-right ratio by 1.2%, and neutron scattering by impurities in the magnesium by 0.8%. The largest correction, from scattering within the CD_2, was determined empirically from the measured left-right ratios at each angle, using CD_2 wall thicknesses of 1.52 mm and 2.67 mm. No correction was made for multiple scattering in the Mg.[16]

From ϵ, the corrected left-right ratio, we calculated P_1P_2, the product of the photoneutron polarization P_1 and the Mg analyzing ability P_2, from

$$P_1P_2 = (1/0.96)[(\epsilon-1)/(\epsilon+1)],$$

where 0.96 was the estimated mean cosine of the angle between the neutron production and scattering planes due to the finite sizes of the experimental components. Finally, from P_1P_2 and P_2 from reference 14 (interpolated to our energies), P_1 was calculated. The results are plotted in Fig. 2. The solid curve is from a theoretical calculation by Kramer,[9,17] who finds the polarization to be given by

$$P(d\sigma/d\Omega) = \gamma_0 \sin\theta,$$

where $d\sigma/d\Omega = a + b\sin^2\theta$ is the differential cross section for photodisintegration. Kawaguchi[5] found an equivalent formula with $\gamma_0 = \pm(2ab/3)^{\frac{1}{2}} \sin\delta_0$, where δ_0 is the singlet-S neutron-proton scattering phase shift. Kramer[17] evaluated γ_0 for $E_\gamma = 2.759$ Mev in the effec-

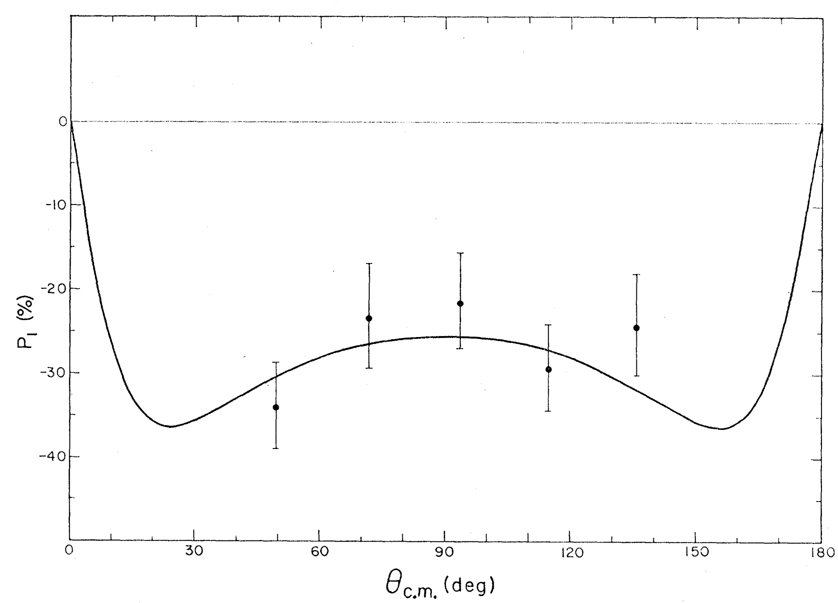

FIG. 2. Polarization of the neutrons from the reaction $D(\gamma,n)H$ with $E_\gamma = 2.753$ Mev. The solid curve is from a theoretical calculation by Kramer as explained in the text.

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tive range approximation. For a singlet range of 2.4×10^{-13} cm and a singlet scattering length of -23.7×10^{-13} cm, $\gamma_0=-40.9$ μb, $a=23.0$ μb, and $b=136.9$ μb. The above theories assume that only dipole transitions are involved and that noncentral forces are not important. We conclude that our experimental data are in satisfactory agreement with the theory. Because the calculated polarization is not sensitive to the effective-range parameters and the experimental errors are relatively large, we cannot derive improved values of the parameters. The experimental results do confirm the predictions of the current phenomenological theory of the neutron-proton system at low energy.

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Elastic Scattering of 11.8-Mev Deuterons from Several Elements

G. Igo,* W. Lorenz, and U. Schmidt-Rohr
Max-Planck-Institut für Kernphysik, Heidelberg, Germany

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The angular distributions of 11.8-Mev deuterons elastically scattered from C, Mg, Al, Ti, Fe, Ni, Cu, Zn, Zr, Nb, Rh, Pd, Ag, Cd, In, Sn, Ta, and Au have been measured. The detector is capable of electronically separating deuterons from other ions which may enter the detector. The data have been taken in 2-degree steps between 20° and 165°. The structure in the angular distribution observed with the light target elements is vanishing with increasing atomic weight. An exception is observed between $A=90$ and $A=120$.

INTRODUCTION

THE elastic scattering of deuterons at moderate energies has been studied by Alford and Slaus[1] at 4 Mev, by Rees and Sampson[2] at 11 Mev, by Cindro and Wall[3] at 13.5 and 15.5 Mev, by Gove[4] at 15 Mev, and by Yntema[5] at 21.6 Mev. Some of the data have been analyzed by Porter,[6] Melkanoff[7], Glassgold,[8] and Hodgson.[9] The angular distributions of elastically scattered deuterons are qualitatively similar to proton, neutron, and alpha-particle elastic scattering data. In particular, apsidal distance plots[10] of differential cross sections for heavy-element data, as in alpha-particle scattering, rise above the Rutherford differential cross section at some critical apsidal distance and then drop monotonically below at smaller apsidal distances. However, the critical apsidal distance for deuterons is larger than that for alpha particles, reflecting the loosely bound structure of the deuteron.[6] Optical model analysis of deuteron data indicates that the real potential is quite similar to that obtained for protons, and the imaginary part of the potential is probably larger for light elements than for heavy elements.[7] Melkanoff has interpreted this as due to the high probability for stripping at the surface of nuclei. Since light nuclei are mainly surface, they require a larger depth.

The present work at 11.8 Mev is extensive. The data have been taken in two-degree steps from about $\theta_{\rm lab}=20°$ to 165° for 18 targets constituted of elements spaced throughout the periodic table, with small statistical errors and good angular resolution. A dE/dx and E system[11] has been utilized to determine that only deuterons were counted.

EXPERIMENTAL PROCEDURE

A collimated beam of 11.8-Mev deuterons in excess of 1 μamp in intensity has been produced using a 100-cm cyclotron. The beam handling system and the scattering

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* Fulbright Fellow 1958–59; present address: Lawrence Radiation Laboratory, University of California, Berkeley, California.

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