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The recent development of a variable-energy polarized proton beam at the Berkeley 88-inch cyclotron has made it possible to extend measurements[1] of the proton polarization induced in the elastic scattering of protons from deuterons below 100 MeV. Polarized protons, available at energies from 12 to 60 MeV with polarizations ranging from 80 to 100%, are produced as recoil protons (near 130° cm) from a liquid-nitrogen-cooled gaseous hydrogen target placed in the alpha-particle beam. This polarized beam facility will be described in detail elsewhere.[2]

It is expected that determinations of polarization in nucleon-deuteron scattering at energies below 100 MeV should provide information useful to the understanding of the very marked difference between the polarization induced in nucleon-nucleon scattering and that resulting from the scattering of the nucleon from a few-nucleon system.[3] Kowalski and Feldman[4] have recently made an impulse approximation (IA) calculation of the polarization in p-d scattering at 150, 90, and 40 MeV; so, we have measured the polarization at 40 MeV in order to make a direct comparison with their prediction.

The experiment was carried out in two steps, the first of which was to determine the polarization of the 40-MeV proton beam. The known[5] 99% polarization (near 130° cm) of 10-MeV protons scattered from He^4 was taken as our starting point. The same center-of-mass energy is achieved with 40-MeV alpha particles incident on a hydrogen target; so, with this condition fulfilled, recoil protons taken at 23.5° (133° cm) with respect to the direction of the incident alpha beam provided a 20-MeV beam polarized to 99%. We then measured the left-right asymmetry, $\epsilon = (L-R)/(L+R)$, in the scattering of this beam from He^4. For elastic scattering, the asymmetry is given by $\epsilon(\theta) = P_1 P(\theta)$, where P_1 is the fractional polarization of the proton beam and $P(\theta)$ is the proton polarization that would be induced in the scattering of unpolarized protons by the target. Thus, from $\epsilon(\theta) = 0.99\, P(\theta)$ we determined that the maximum polarization in p-He^4 scattering at 20 MeV occurs at $\theta_{cm} = 126°$ with a value of + 0.82 ± 0.03. The sign is given in accord with the Basle convention (positive polarization in the direction of $\vec{k}_{in} \times \vec{k}_{out}$) The procedure was repeated at an alpha beam energy of 80 MeV, which produced at 126° cm. a 41-MeV beam of recoil protons with a polarization $P_1 = +\, 0.82 \pm 0.03$ and an intensity of approximately 4×10^7 protons/sec for 10μa of incident alpha particles. This beam was then scattered from a deuterium gas target at a mean energy of 40.3 ± 0.6 MeV, and the measured asymmetries gave the polarizations $P(\theta) = \epsilon(\theta)/0.82$.

Eight detectors, consisting of CsI crystals mounted on Dumont 6363 photomultiplier tubes, were used to record simultaneously asymmetries at four scattering angles. Pulses from each detector were routed to separate quadrants of two 400-channel pulse-height analyzers. Halfway through each run, left-right detector pairs with their associated electronics were interchanged in order to minimize systematic errors and to correct for differences in detector efficiencies and geometry. The angular resolution was ± 1.5 deg.

Figure 1 shows pulse-height-analyzer spectra taken at equal left and right scattering angles in the forward hemisphere, and one sees, in addition to the peak of elastically scattered protons, a peak of recoil deuterons. Such recoil-deuteron asymmetries gave the asymmetries of the associated backward scattered protons, and, thus, provided consistency checks on the back-angle proton data. The target-empty background and the inelastic proton continuum were subtracted from each spectrum to give the total counts in the elastic peak.

Our results are presented in Table I and Figure 2. The listed uncertainties in $P(\theta)$ include the statistical error in the number of counts in the peak and uncertainties in the background and inelastic subtractions. The uncertainty in P_1, which results only in a change in scale, is not included. Figure 2 also shows the results calculated by Kowalski and Feldman[4] in the approximation that the scattering process is a superposition of the single scatterings of the incident nucleons from each of the target nucleons. Multiple scattering effects and pickup scattering[6,7] were not included. The CA curve results from the Chew form of the IA, applicable to regions of small momentum transfers. The LA (linear approximation) curve results from including larger momentum transfers but not considering off-the-energy-shell effects. Finally, the FA curve results from the inclusion of off-the-energy-shell scattering. Even though one ignores the angular region of pickup scattering, $\theta_{cm} > 130^{\circ}$, our results do not agree quantitatively with any one of the calculated curves. In fact, the discrepancy between experimental and calculated results increases in going to the more complete versions of the calculation. The FA result provides the best fit to data at 150 MeV[7], so the non-applicability of the IA at 40 MeV or the importance of multiple scattering corrections[8] at this energy is indicated.

Continued analysis of our results is in progress, and a more detailed report will be made at a later date.

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FOOTNOTES AND REFERENCES

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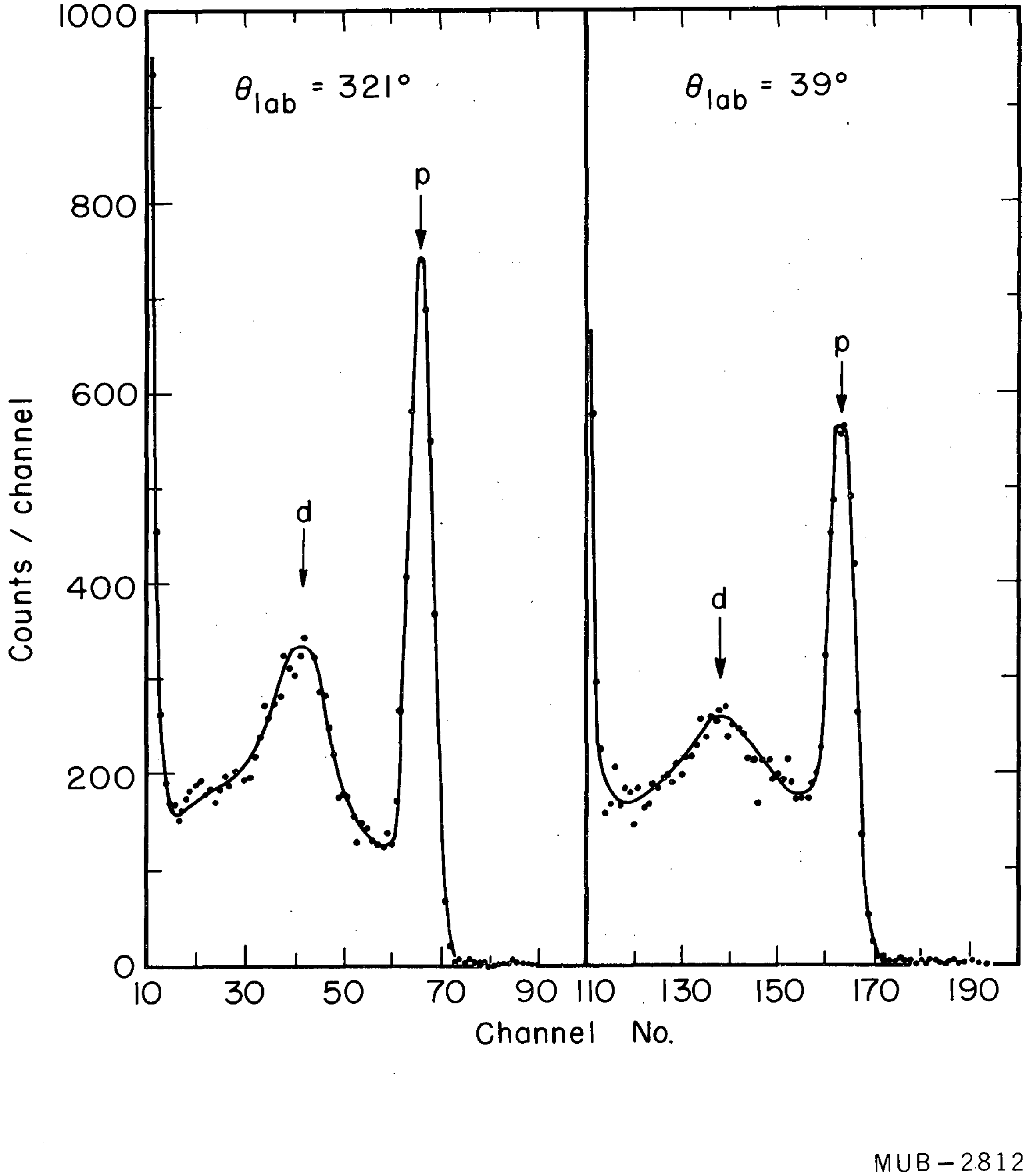
Table I. Proton polarization in p-d elastic scattering at 40 MeV. Column 3 lists where the proton (p) as recoil deuteron (d) asymmetries were used to give the polarization.

θ_L	θ_{cm}	Particle	$P(\theta)$
20	30.1	p	+ 0.093 ± 0.003
25	37.5	p	+ 0.124 ± 0.009
30	44.9	p	+ 0.103 ± 0.010
35	52.1	p	+ 0.129 ± 0.011
39	57.9	p	+ 0.098 ± 0.009
45	66.2	p	+ 0.040 ± 0.016
50	73.0	p	- 0.012 ± 0.017
55	79.7	p	- 0.095 ± 0.016
45	87.7	d	- 0.250 ± 0.022
65	92.5	p	- 0.295 ± 0.016
70	98.6	p	- 0.282 ± 0.014
39	100.3	d	- 0.328 ± 0.061
76	105.6	p	- 0.332 ± 0.023
35	109.7	d	- 0.374 ± 0.033
84	114.3	p	- 0.392 ± 0.016
30	119.8	d	- 0.385 ± 0.045
95	125.3	p	- 0.311 ± 0.030
100	129.9	p	- 0.367 ± 0.036
106	135.1	p	+ 0.060 ± 0.041
114	141.5	p	+ 0.49 ± 0.20

FIGURE CAPTIONS

Figure 1. Pulse-height spectra taken at equal right and left scattering angles ($\theta_{lab} = 39^{\circ}$), showing the elastic proton peak (p) and the recoil deuteron peak (d).

Figure 2. Proton polarization, $P(\theta)$, in p-d elastic scattering at 40 MeV. The curves labeled CA, LA, and FA are results from impulse approximation calculations of reference 4.



1000
800
600
400
200
0
Counts / channel
θ_{lab} = 321°
θ_{lab} = 39°
p
d
p
d
10
30
50
70
90
110
130
150
170
190
Channel No.
MUB-2812

Fig. 1

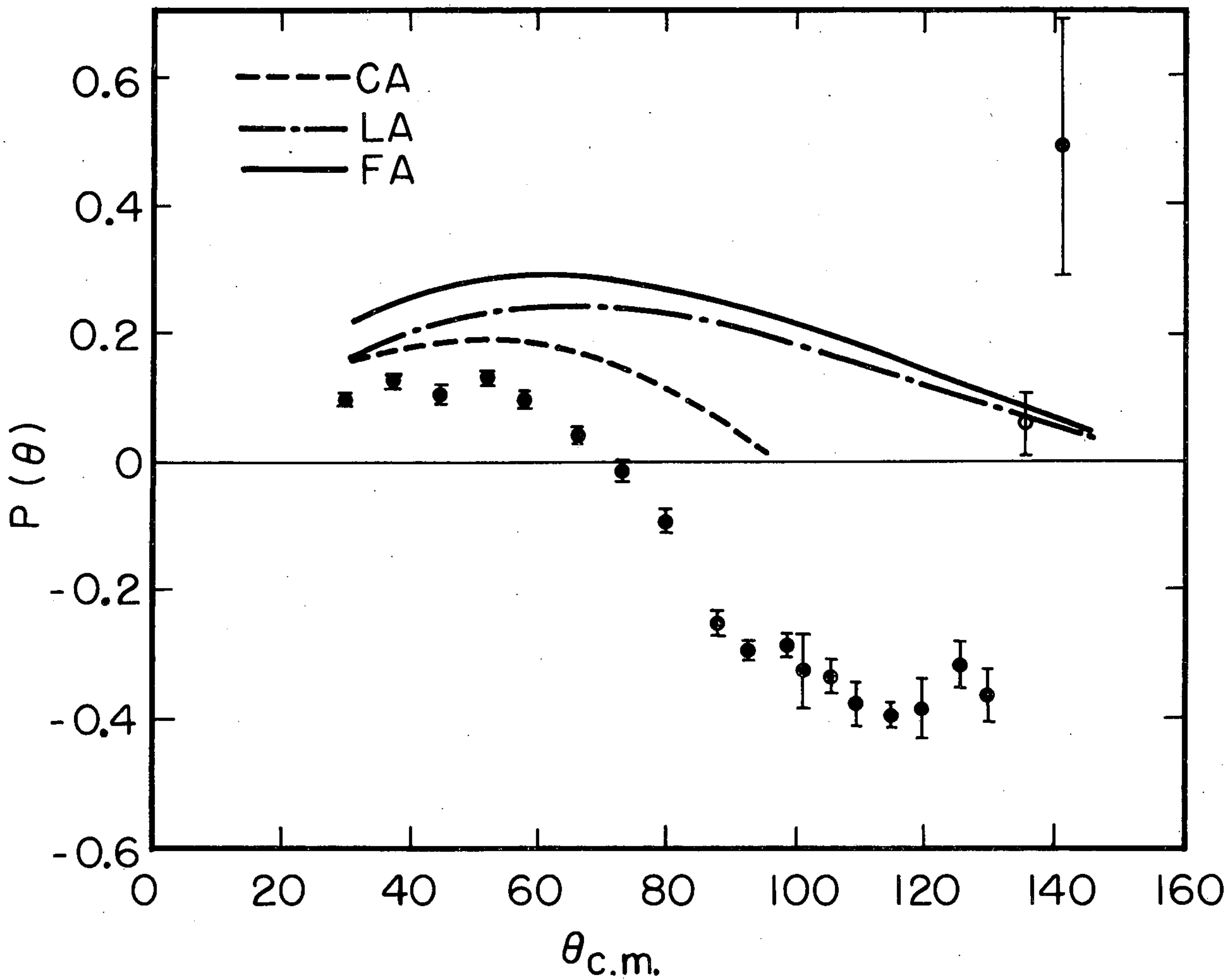


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Fig. 2