Polarization of Scattered Protons near 17 Mev*

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Experimental angular distributions of the polarization of protons elastically scattered from magnesium, calcium, copper, silver, and gold near 17 Mev are presented, and comparison with certain theoretical calculations made. Data are also given on the polarization of inelastic protons scattered from magnesium with $Q=-1.37$ Mev. The familiar double-scattering method was used, with carbon serving as second scatterer. It is concluded that appreciable elastic polarization may be universally expected at this energy, and that therefore some form of spin-orbit interaction is important.

INTRODUCTION

MEASUREMENT of the polarization of nucleons scattered from nuclei has been of considerable interest in recent years, both at low[1] and at high energies.[2,3] These data have proved valuable in the interpretation of scattering phenomena. However, little attention has been given to the medium energy range, from about 5 to 60 Mev. Indeed, extrapolation of some of the high-energy results appeared to indicate that polarization of protons scattered from nuclei would probably disappear around 50 Mev.[3]

More recent results at 10 Mev by Rosen and Brolley,[4] and at 17 Mev by Brockman[5] have shown that such a conjecture was not true, and that instead significant polarization effects could be observed at medium energies. In particular, Brockman measured the polarization of protons elastically scattered from helium and carbon at 17 Mev. Measurements of polarization of protons scattered from five additional nuclei at this same energy are reported here.

THEORETICAL BACKGROUND

Since the various methods of analyzing polarization data have been quite thoroughly treated in the literature,[1–3,6–10] only a few points especially applicable to the medium-energy situation will be outlined here.

The optical model of the nucleus has been widely used for fitting elastic cross section data. As originally proposed,[11] this approach consisted of replacing the nucleus with a complex, central square well. Perhaps the most successful medium-energy cross section fits were made by Saxon and Woods[12] to the 17-Mev data of Dayton and Schrank.[13] This group used a complex central well with a gradually sloping shape. In general, their fits were quite good to about the second diffraction minimum, but then went out of phase with the experimental points.

Fermi,[6] and, independently, Heckrotte and Lepore[7] were the first to modify the central optical potential in order to calculate polarizations. Their modification consisted of adding a noncentral spin-orbit term proportional to the gradient of the central form factor, in analogy to the Thomas precession term familiar in atomic problems. Fermi[14] has given a physical argument for this form. Almost all subsequent theoretical treatments have employed this modified optical potential, though some have used a non-Thomas spin-orbit form factor.[8]

Fermi[6] and Heckrotte and Lepore[7] used the Born approximation in their computations. However, Heckrotte[15] soon showed that in Born-approximation polarization is quite independent of well shape. Later Levintov[16] showed that the Born approximation is valid for polarization calculations only at high energies and at angles considerably smaller than the first diffraction minimum of the elastic cross section. Since these conditions are not met in the work considered in this paper, a more exact treatment is required for quantitative interpretation. Further, as many partial waves are significant at this energy for all but the lightest nuclei, a machine calculation is implied.

By means of a machine calculation, Bjorklund and Fernbach[9] were able to make excellent fits to 14-Mev neutron differential cross section data, using an optical

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[1] See, e.g.: M. Heusinkveld and G. Freier, Phys. Rev. **85**, 80 (1952); P. Huber and E. Baumgartner, Helv. Phys. Acta **26**, 423 (1953); Adair, Darden, and Fields, Phys. Rev. **96**, 503 (1954); A. Remund, Helv. Phys. Acta **29**, 545 (1956); M. Scott, Phys. Rev. **110**, 1398 (1958).

[2] See, e.g.: Oxley, Cartwright, and Rouvina, Phys. Rev. **93**, 806 (1954); DeCarvalho, Marshall, and Marshall, Phys. Rev. **96**, 1081 (1954); Meshcheryakov, Nurushchev, and Stoletov, Zhur. Eksptl. i Teoret. Fiz. **31**, 361 (1956) [translation: Soviet Phys. JETP **4**, 337 (1957)]; Chamberlain, Segrè, Tripp, Weigand, and Ypsilantis, Phys. Rev. **102**, 1659 (1956); Chestnut, Hafner, and Roberts, Phys. Rev. **104**, 449 (1956).

[3] Dickson, Rose, and Salter, Proc. Phys. Soc. (London) **A68**, 361 (1955).

[4] L. Rosen and J. Brolley, Phys. Rev. **107**, 1454 (1957).

[5] K. Brockman, Phys. Rev. **110**, 163 (1958).

[6] E. Fermi, Nuovo cimento **11**, 407 (1954).

[7] W. Heckrotte and J. Lepore, Phys. Rev. **94**, 500 (1954).

[8] B. Malenka, Phys. Rev. **95**, 552 (1954); Snow, Sternheimer, and Yang, Phys. Rev. **94**, 1073 (1954); G. Erickson and W. Cheston, Phys. Rev. **111**, 891 (1958).

[9] F. Bjorklund and S. Fernbach, Phys. Rev. **109**, 1295 (1958).

[10] L. Wolfenstein, *Annual Review of Nuclear Science* (Annual Reviews, Inc., Palo Alto, 1956), Vol. 6, p. 43.

[11] Feshbach, Porter, and Weisskopf, Phys. Rev. **90**, 166 (1953); **96**, 488 (1954); Fernbach, Serber, and Taylor, Phys. Rev. **75**, 1352 (1949).

[12] D. Saxon and R. Woods, Phys. Rev. **106**, 793 (1957).

[13] I. Dayton and G. Schrank, Phys. Rev. **101**, 1358 (1956).

[14] E. Fermi, Suppl. Nuovo cimento **2**, 84 (1955).

[15] W. Heckrotte, Phys. Rev. **94**, 1797 (1954).

[16] I. Levintov, Doklady Akad. Nauk S.S.S.R. **107**, 240 (1956) [translation: Soviet Phys. Doklady **1**, 175 (1956)].

potential with a spin-orbit term. From the parameters so obtained they also computed polarizations, and found that these were appreciable. Bjorklund[17] repeated this procedure for the protons scattered from nuclei at 17 Mev. His fits (see, e.g., Fig. 2) were much better than those of Saxon and Woods,[12] and his predicted polarizations were appreciable in this case as well. Therefore, it appeared that a spin-orbit interaction might well be important at medium, as well as at low and high energies.

However, there remained an ambiguity in the values of Bjorklund's optical parameters. Since cross section and polarization measurements are complementary in that calculation of both quantities involves the same parameters in different combinations, it was felt that additional polarization data at 17 Mev would not only give an indication of the degree of importance of the spin-orbit interaction, but might also serve to reduce the range of ambiguity of the parameters themselves.

EXPERIMENTAL PROCEDURE

Measurements were made by the familiar double-scattering method first suggested by Mott,[18] and discussed by many, including Wolfenstein.[10] In these measurements the target containing the nucleus of interest served as first scatterer, while carbon served as second scatterer. In each case the asymmetry, e, was measured at 45 degrees to the right and left of the second scatterer. This asymmetry is defined as the difference in the total number of counts on each of the two sides, divided by the sum of the counts on the two sides. If now P_1 and P_2 are, respectively, the polarizations produced by targets 1 and 2 on a previously unpolarized beam of particles, then the unknown polarization, P_1, may be found through the relation $e=P_1P_2$, provided P_2 is known, or vice versa. This relation is valid if the first and second scattering planes coincide.

While most of Brockman's data were taken with helium as the second scatterer, he did use carbon in a few instances, and noted the comparative advantages of the two nuclei.[5] Briefly, carbon is superior to helium from the point of view of energy resolution and background, but is more sensitive to errors in alignment, and cannot yield results as accurate as can helium, since polarization of protons scattered from the latter is known to a higher degree of certainty. Nonetheless, since great accuracy was not the prime concern of the present work, it was decided that the easier to handle carbon was to be preferred as second scatterer.

The general experimental arrangement is shown in Fig. 1; it is quite similar to that described by Brockman.[5] The first scattering angle, θ_1, was variable from 30 to 135 degrees, while the second scattering angles, θ_2, were fixed at 45 degrees. A foil containing the nucleus of interest was centered in the first scattering chamber,

[17] F. Bjorklund (private communication).
[18] N. Mott, Proc. Roy. Soc. (London) **A124**, 425 (1929); **A135**, 429 (1932).

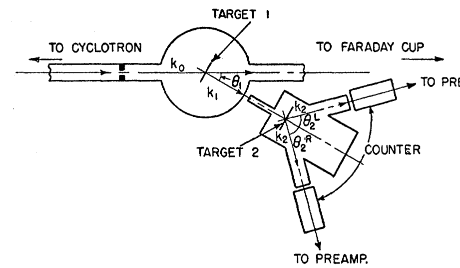

FIG. 1. Schematic diagram of experimental double-scattering arrangement.

while a foil containing carbon was placed in the second chamber. This second scattering chamber was clamped to a bar, one end of which pivoted about the center of the first chamber, varying the angle θ_1. The axis of this chamber was normal to the second target, and intersected the center of the first target, which was also the point of intersection of the incident proton beam from the cyclotron. The darkening of a Teflon foil placed in the first target position and bombarded for a few minutes checked the latter condition. This procedure was repeated several times during the course of the experiments; in no case was the beam spot more than $\frac{1}{32}$ inch off the target center. Exit apertures were of equal height above the scattering table so that the first and second scattering planes coincided.

After being scattered from the second foil and collimated by the $\frac{3}{8}$-inch exit apertures, the twice scattered protons were stopped in $\frac{1}{8}$-inch Harshaw NaI(Tl) crystals. Pulses were detected by Dumont 6292 photomultiplier tubes, shaped by standard cathode followers, and recorded by multichannel pulse-height analyzers. At the time these experiments were performed, two such analyzers were available in the cyclotron area: an Atomic Instruments 20-channel analyzer, and a 100-channel analyzer described elsewhere.[19] Because of the long counting periods involved, recording both the left and the right side simultaneously was imperative. However, the long (43-millisecond) 100-channel dead time did introduce an instrumental asymmetry. The effect never amounted to more than 4%, was easily calculated, and often checked by permutation of the two analyzers. Permutation of the other elements of the system—in particular the photomultipliers and cathode followers—insured that no asymmetry due to an overlooked effect was introduced. Frequent checks were also made with the first and second chambers used by Brockman.[5]

Since it was desirable to record a background, incident charge was collected by a Faraday cup, and measured with a beam current integrator. Background runs were then taken for incident charge equal to that of the main run. In recording background, $\frac{1}{16}$-inch slabs of brass were placed in front of the scintillation counters, and the rest of the apparatus left undisturbed.

[19] Birk, Braid, and Detenbeck, Rev. Sci. Instr. **29**, 203 (1958).

In particular, both scatterers remained in place. This thickness brass was sufficient to stop all elastic protons, but allowed neutrons and gamma rays to pass almost unimpeded. Charged particles were, in all cases, produced with negative Q values,[20,21] and therefore never contributed to the apparent elastic peaks. Sufficient shielding was used so that in almost all cases the background was no higher than about 5% of the total elastic peak area. In the very rare cases where it was as high as 30%, the possibility that the reactions in the $\frac{1}{16}$-inch brass contributed to the apparent backbround could not be ignored. However, checks made alternately with and without the first and second targets showed that such contributions were at best negligible.

Raw data minus background were plotted, and the symmetry of each separate elastic peak required for acceptance. Raw asymmetries were then computed from these peak areas. All points were run at least three times, with the roles of the 20- and 100-channel analyzers permuted in at least one of these runs. An average was then taken as the final raw asymmetry.

The incident proton beam was obtained from the Princeton 19-Mev FM cyclotron. Since this machine produced only a small beam current (about 5 to 10 millimicroamperes) at the first target position, and since double scattering is a highly improbable occurrence, it was necessary to use thick foils and large apertures to obtain realistic counting rates. First scattering foils ranged from about 60 to 120 mg/cm^2 (i.e., a 16-Mev proton lost about 0.8 to 1.5 Mev in these targets), while a 40-mg/cm^2 polystyrene foil served as second scatterer in almost all cases. Angular resolution of the first scattering was about ± 4 degrees. Nevertheless, counting rates were still very low. An "average" point gave about 1 or 2 counts per minute, so that runs of three or four hours or longer were required to yield the statistics presented. With such low counting rates, counter efficiencies were virtually 100%, and pile up and, usually, dead-time problems were nonexistent. However, because of the thick foils, the energy resolution of the elastic peak was usually about 15%, in a few cases even worse. Hence, some inelastic protons were not resolved from the elastic. The effects of this factor on the experimental uncertainties will be discussed presently.

To obtain the best possible energy resolution under the given conditions, in each case the first target was turned so that its normal bisected the first scattering angle. As this made the effective target thickness different at each angle, it was necessary to change the incident beam energy in order to keep the mean energy of first scattering constant with angle. The mean energy of the elastic peaks was certain to about 0.2 Mev, the uncertainties being due to incident beam spread, cyclotron fluctuations, and uncertainties in setting the cyclotron energy by means of the current in the cyclotron magnet.

All first targets were metallic foils containing the natural isotopic mixture. With the exception of calcium, these were obtained commercially. The calcium foil was rolled from a small block of the element under dry mineral oil, and stored in this oil until ready for use. It was then cleaned in dry benzene, and placed in the first chamber. Even at the running pressures (of order 10^{-4} mm/Hg) there was sufficient oxygen to form an oxide coating. However, this coating was sufficiently thin so that the contamination was less than 5% of the thick target. To check this, points were repeated at the beginning and end of a series of runs (i.e., with a fresh and a contaminated target surface), and statistical disagreement noted in only one instance (45 degrees—the elastic minimum). This angle was repeated with a fresh target, and agreement obtained. Beyond 70 degrees the oxygen elastic peak was resolved from the calcium, but was rarely observed above background.

Brockman[5] found that the polarization of protons scattered from carbon at 45 degrees is a function of energy. Since in these experiments the mean energy of second scattering was a function of first scattering angle, it was necessary to have a calibration curve of the polarization *vs* angle for carbon. Brockman's data served as a basis, and a number of other points in the 14- to 18-Mev range were measured by first scattering from graphite at 45 degrees, setting either E_1 or E_2 at an energy at which the polarization was known, and fixing the other energy at a desired value by means of the cyclotron magnet and absorber foils placed between the two scattering foils. The curve so measured was in statistical agreement with Brockman's results, and also showed that a calculation of asymmetries due to finite geometry was correct in predicting a negligible correction. Therefore, the raw asymmetries obtained as described above, and the calibration curve giving P_2 as a function of energy, permitted determination of the unknown polarization, P_2.

RESULTS

The polarization of protons elastically scattered from magnesium, calcium, copper, silver, and gold is given as a function of angle in Tables I–V; Table VI gives the polarization of protons inelastically scattered from magnesium with $Q=-1.37$ Mev. In each case the mean energy of first scattering was chosen so that the proton had 16.4 Mev in the center-of-mass system. Wolfenstein's[10] sign convention was adopted; that is, the normal to the first scattering plane is taken in the direction $\mathbf{k}_0\times\mathbf{k}_1$, where $\mathbf{k}_0$ and $\mathbf{k}_1$ are, respectively, the incident and scattered wave vectors.

Experimental uncertainties are chiefly statistical, and were computed by means of the well-known expression for root mean square error. Permutation of the various elements of apparatus, and checks with the

[20] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **27**, 77 (1955); P. Endt and C. Braams, Revs. Modern Phys. **29**, 683 (1957).
[21] A. Wapstra, Physica **21**, 367 and 385 (1955).

arrangement previously described by Brockman[5] showed that any errors due to misalignment were well within statistical limits.

In a few cases, failure to resolve inelastic protons from the elastic resulted in uncertainties greater than the statistical limits. Let $P(E+I)$ and $P(I)$ be, respectively, the total polarization computed from the unresolved experimental peaks, and the actual mean polarization of the unresolved inelastic protons; let $P(E)$ be the actual elastic polarization. Then if γ is the ratio of the cross section of the unresolved inelastic protons to the total cross section (i.e., elastic plus unresolved inelastic), a straightforward calculation shows that the uncertainty due to this effect is

$$\Delta P \equiv P(E+I)-P(E) = -\gamma[P(E+I)-P(I)].$$

To apply this equation, γ was estimated by comparing well-resolved single scattered spectra to corresponding double spectra, and an *a priori* value of zero given to $P(I)$. This assignment was based on the observation that, very roughly speaking, those inelastic polarizations that have been observed are usually smaller than, and of the same sign as, the corresponding elastic polarization at the same angle.[5] Of course, this assignment is open to question, and a different value for $P(I)$ could change the uncertainty due to this effect. The few cases where the given procedure resulted in an uncertainty greater than the statistical limits are discussed below.

Magnesium.—The many levels of Mg^{25} and Mg^{26} [20] were not resolved from the elastic and −1.37-Mev peaks from Mg^{24}. However, these are inelastic levels in 10% isotopes, and therefore introduced negligible difficulty. In order to increase the separation of the elastic and −1.37-Mev peaks, a 70-mg/cm² thickness of aluminum absorber was introduced in front of the counters. In all cases the ratio of elastic peak to valley was at least 4. This procedure had the adverse effect of depressing the −1.37-Mev peak further into the background, as reflected in the statistics.

Calcium.—The first excited state of the 96% isotope 40 is at 3.35 Mev,[20] and was well resolved from the elastic peak. However, the oxygen contamination, previously noted, was unresolved at angles smaller than 70 degrees, but only caused difficulty at 45 degrees. Here γ was estimated to have an upper limit of 0.1, and the uncertainties extended accordingly.

Copper.—Both stable isotopes (63 and 65) have a number of levels below about 1.5 Mev.[22] According to Dayton and Schrank,[13] levels around 1 Mev are the first to show significant yields compared to the elastic peak. These levels were only partially resolved in the double spectra; comparison with well-resolved single spectra, however, indicated that the resulting uncertainties were greater than statistical only at 65, 70, and 75 degrees.

Silver.—Dayton and Schrank[13] observed an inelastic level at 0.44 Mev that was never resolved in the double spectra. From the asymmetry of single spectra it was estimated that only the resulting uncertainties on points from 85 to 100 degrees were greater than sta-

TABLE I. Polarization of protons elastically scattered from magnesium at 17.8±0.2 Mev.

$\theta_{c.m.}$	P	$\theta_{c.m.}$	P	$\theta_{c.m.}$	P
34.3	−0.12±0.05	62.0	+0.10±0.06	102.3	−0.08±0.10
41.5	−0.20±0.06	72.2	−0.18±0.06	112.2	+0.52±0.10
46.6	+0.28±0.06	82.3	−0.30±0.06	122.0	+0.28±0.12
51.8	+0.44±0.06	92.3	−0.24±0.08		

TABLE II. Polarization of protons elastically scattered from calcium at 17.3±0.2 Mev.

$\theta_{c.m.}$	P	$\theta_{c.m.}$	P	$\theta_{c.m.}$	P
30.7	0 ±0.05	61.2	−0.56±0.06	96.5	+0.23±0.10
35.8	+0.05±0.05	66.3	−0.65±0.08	106.4	+0.04±0.10
40.9	+0.15±0.06	76.5	−0.31±0.08	116.3	−0.06±0.10
46.0	−0.05±0.08	86.5	+0.51±0.08	126.2	−0.22±0.16
51.1	−0.18±0.06				

TABLE III. Polarization of protons elastically scattered from copper at 17.0±0.2 Mev.

$\theta_{c.m.}$	P	$\theta_{c.m.}$	P	$\theta_{c.m.}$	P
30.5	+0.24±0.04	60.7	−0.22±0.06	91.0	−0.22±0.08
35.5	+0.18±0.05	65.7	$+0.36^{+0.08}_{-0.06}$	101.0	−0.40±0.08
40.5	0 ±0.06	70.8	$+0.54^{+0.10}_{-0.06}$	110.9	−0.38±0.10
45.6	−0.19±0.06	75.8	+0.52±0.06	120.8	+0.80±0.15
50.6	−0.31±0.06				

TABLE IV. Polarization of protons elastically scattered from silver at 16.8±0.2 Mev.

$\theta_{c.m.}$	P	$\theta_{c.m.}$	P	$\theta_{c.m.}$	P
30.2	−0.04±0.04	55.4	+0.19±0.04	85.6	−0.24±0.08
35.3	−0.09±0.04	60.4	+0.22±0.06	95.6	0 ±0.10
40.3	+0.03±0.04	65.5	+0.17±0.06	105.5	+0.23±0.10
45.3	+0.07±0.05	75.5	−0.04±0.05	120.5	−0.55±0.13
50.3	+0.14±0.05				

TABLE V. Polarization of protons elastically scattered from gold at 16.5±0.2 Mev.

$\theta_{c.m.}$	P	$\theta_{c.m.}$	P	$\theta_{c.m.}$	P
30.0	−0.02±0.04	55.3	+0.02±0.04	85.3	−0.05±0.08
35.1	−0.06±0.04	60.3	−0.07±0.06	95.3	+0.20±0.08
45.2	+0.05±0.04	70.3	+0.27±0.06	105.3	−0.07±0.08
50.2	+0.13±0.05	75.3	+0.17±0.07	120.3	+0.29±0.10

TABLE VI. Polarization of inelastically scattered protons from magnesium. $Q=-1.37$ Mev; $E_1=17.8$ Mev.

$\theta_{c.m.}$	P	$\theta_{c.m.}$	P	$\theta_{c.m.}$	P
34.3	−0.14±0.12	72.2	+0.44±0.14	102.3	+0.08±0.12
41.5	−0.32±0.14	77.2	+0.27±0.14	112.2	+0.08±0.12
51.8	+0.26±0.14	82.3	+0.19±0.14	122.0	−0.22±0.14
62.0	+0.40±0.14	92.3	−0.34±0.14		

[22] Mazari, Buechner, and DeFigueiredo, Phys. Rev. **108**, 373 (1957).

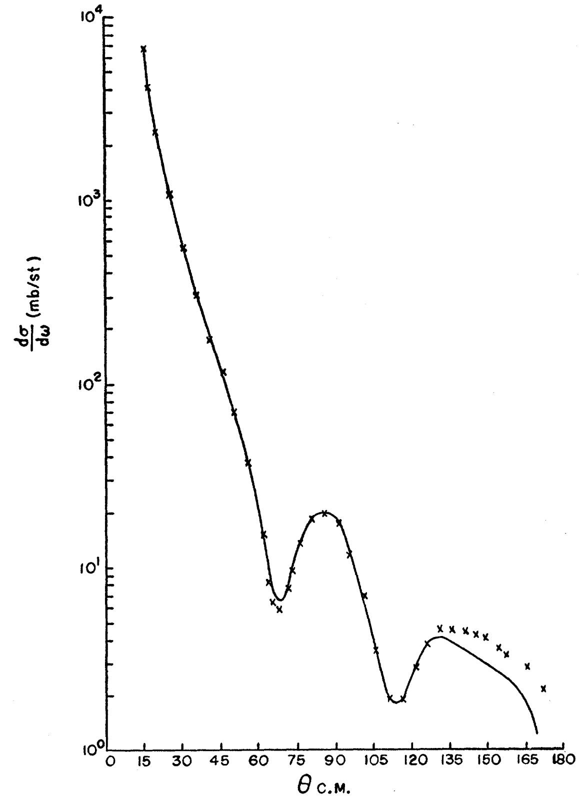

FIG. 2. Optical fit by Bjorklund to the proton elastic cross section of copper at 17.0 Mev (data by Dayton and Schrank).

tistical. The levels observed by Cohen[23] around 2 Mev were always resolved.

Gold.—Dayton and Schrank[13] pointed out that there are many low-lying levels in gold, but that their contribution is small. No level unresolved in the double spectra, but resolved in single spectra was more than a negligible fraction of the elastic peak; those unresolved from even the single peaks contributed no noticeable distortion. Hence, it was felt the statistical uncertainties were sufficient in all cases.

CONCLUDING REMARKS

A few qualitative observations may be made concerning these data. There appears to be little doubt that the polarization of protons elastically scattered from nuclei at medium energies is an almost universal phenomenon, and that large polarizations may be expected. These experiments have shown polarization in five nuclei ranging from mass 24 to 197, while polarization from helium and carbon has been previously reported.[5] Further, the polarizations are roughly correlated with the differential cross sections, as may be seen by comparing these data with the differential cross section data of Dayton and Schrank.[13] Many extremum points on the polarization curves fall near the diffraction minima of the corresponding elastic cross sections, suggesting that polarization is a diffraction effect, and indicating that a spin-orbit term is a necessary part of any optical potential.

The quantity $A^{\frac{1}{3}}\sin(\theta/2)$ is found to have an approximately constant value for the successive extremum polarization angles for each nucleus in this series, as well as for the carbon data reported by Brockman.[5]

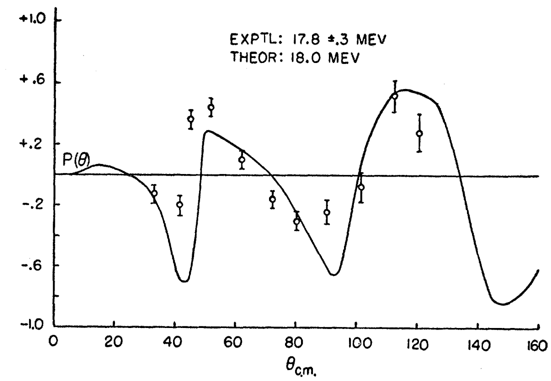

FIG. 3. Optical calculation (Bjorklund) and experimental points for the polarization of protons elastically scattered from magnesium.

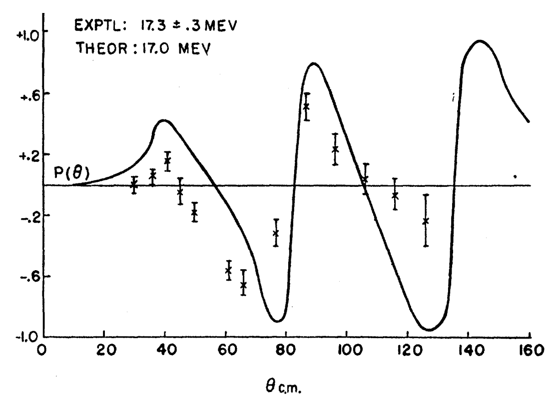

FIG. 4. Optical calculation (Bjorklund) and experimental points for the polarization of protons elastically scattered from calcium.

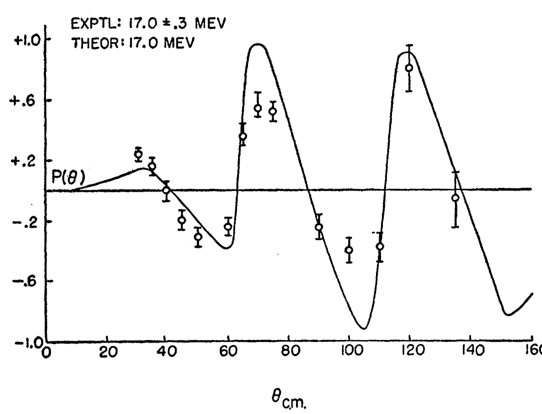

FIG. 5. Optical calculation (Bjorklund) for the polarization of protons elastically scattered from zinc, and experimental points for the polarization from copper.

[23] B. Cohen, Phys. Rev. **105**, 1547 (1957).

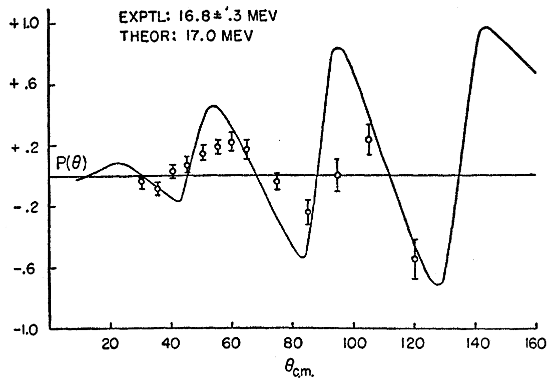

FIG. 6. Optical calculation (Bjorklund) and experimental points for the polarization of protons elastically scattered from silver.

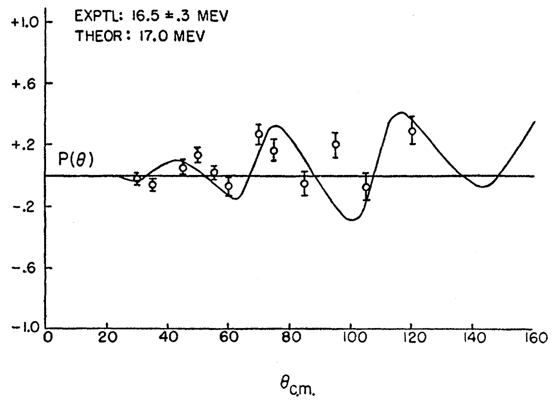

FIG. 7. Optical calculation (Bjorklund) and experimental points for the polarization of protons elastically scattered from gold.

Since this quantity is proportional to the product of momentum transfer by nuclear radius, a diffraction mechanism is again suggested. It also appears that the spin-orbit force involved is common to all nuclei, and, extrapolating from Brockman's results, is attractive in states in which the spin and orbital angular momenta are parallel. Finally, the decreasing magnitude of the polarization with increasing mass may conceivably be attributed to the increasing importance of the Coulomb repulsion.[17]

As has been noted, any quantitative fit to these data would probably require a machine calculation. No actual fit has yet been attempted, but Bjorklund[17] has made some predictions based on fits to differential cross section data, as discussed earlier. These are shown, along with the experimental data, in Figs. 3–7. His nuclear potential is described in the literature,[9] and consisted of a real Saxon[12] central well, an imaginary Gaussian central well, and a real (real at these energies) spin-orbit well proportional to the gradient of the Saxon form factor. Figure 2 shows one of his typical cross-section fits, from which he derived the optical parameters and calculated the polarizations.

Figures 3–7 show that the predictions are in only qualitative agreement with experiment. A few remarks should be made in this regard. First, the finite angular resolution in the experiments could serve to depress the peaks. Second, Bjorklund[17] has shown that his curves are quite energy dependent, and most of the theoretical and experimental curves in Figs. 3–7 are not at exactly the same energies. Washouts due to target thickness may also help to explain some of the discrepancies. Third, the predictions are quite sensitive to variations in the optical parameters; in particular, to the imaginary well depth and thickness of the Gaussian surface.[17] Bjorklund has stated that better agreement could doubtless be obtained if the experimental curves were fit directly. Finally, polarization is much more an interference phenomenon than diffraction scattering,[10] and the optical model may indeed prove to be too crude to explain it in all detail.

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