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Proton Polarization Measurements around 17 MeV

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Abstract. The work done on proton polarization at Princeton University for energies around 17 MeV is reviewed. The greatest emphasis is given to the work on proton-alpha polarization, but the other work of the author and his successor, W. A. Blanpied, is discussed.

This paper is a review of the polarization work done at Princeton University using protons with energies around 17 MeV [1, 2, 3][1]). The work was begun and carried through an initial phase by the author. In this period the instruments and techniques for measuring proton polarization in this energy region were developed and a few measurements were made. The second phase of the work was performed by W. A. Blanpied. He continued the work and has made an important series of polarization measurements. While the results of Dr. Blanpied will be recalled here, the paper will deal mainly with the work of the author.

The work was begun in 1955. It was motivated by the results that were at that time being found at very high energies. The idea was simply that the same sort of thing might be found at medium energies. There were theoretical reasons to support the idea, but there was little theoretical guidance concerning what might be expected, i.e., where to look and what magnitude might be found.

One way of proceeding might have been to set up a double scattering apparatus and to try various target materials and various scattering angles until an effect was found. The pit fall in this is that the asymmetry, which is the measured quantity, is the product of the polarizations for the two scattering events. Unless these polarizations are large, the asymmetry will be small. With no guarantee that polarizations in this energy region were large, and it was generally thought at that time that they might be rather small, this sort of procedure seemed a risky thing to try.

A much better technique is to use an event with a large known polarization for either the first or second scattering event. In 1955 there was only one suitable event that was known and tested. This was the scattering of protons by helium. The polarization to be expected in

[1]) Numbers in brackets refer to References, page 268.

this process had been calculated from the nuclear scattering phase shifts deduced from cross section measurements for energies up to 3.5 MeV [4]. The existence of the predicted polarization had been confirmed by a double scattering experiment [5]. This polarization measurement was in fact a crucial test deciding between two mathematically equivalent sets of phase shifts extracted from the scattering data.

Figure 1 shows a contour plot of the polarization in proton-alpha scattering as a function of laboratory energy and angle for energies up to 18 MeV. The values here have been calculated from phase shifts deduced from differential cross section measurements. Measured values of polarization played no role in the construction of the chart. No great accuracy is claimed for the values shown. The purpose of the calculations that are represented here was only to serve as a guide in the design of experimental apparatus.

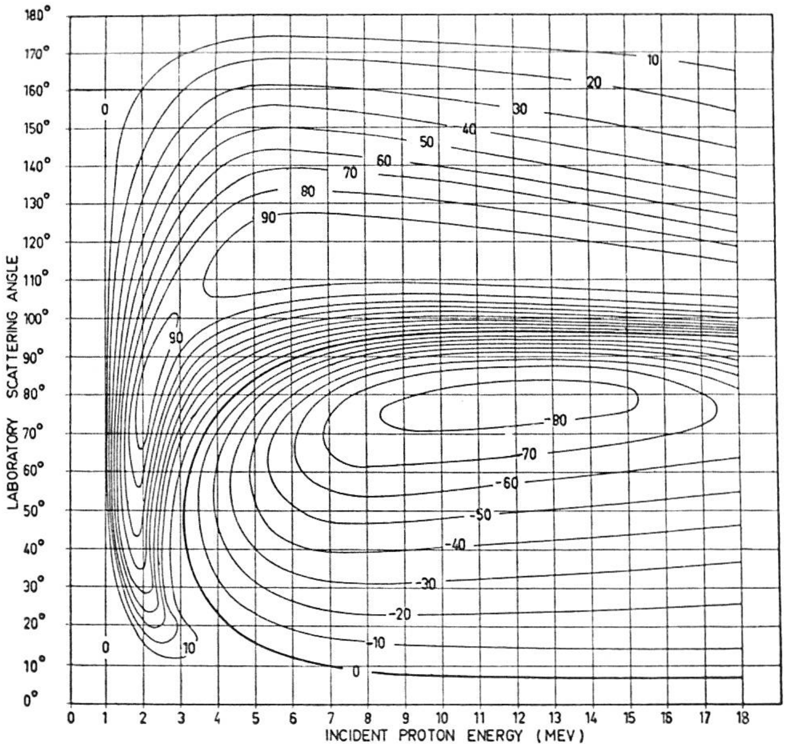

Figure 1

Contour plot of proton alpha polarization as a function of laboratory energy and laboratory scattering angle

The region of the chart below 3.5 MeV was the part for which values of polarization had been published in 1955. We tried to set up an experiment using only this information. An apparatus was built in which the first scatterer was the material under investigation. Scattered particles were then reduced in energy to the region of 2.5 MeV by letting them pass through foils and were scattered the second time by helium at 90.

The apparatus was a complete failure for nothing recognizable was ever observed. The reason for the failure lay in the fact that counters were used as detectors. Success might have been achieved with nuclear emulsions.

When the attempt to use the 2.5 MeV polarization failed it was decided to investigate the polarization predicted by scattering data for higher energies. Phase shifts for measured cross sections had been found for energies up to 9.5 MeV [6]. A calculation using these values revealed the part of the chart up to this energy. A strong maximum appeared to be developing in the region of 60° to 80°, and it seemed that this maximum might persist up to still higher energies. A region of strong polarization at more forward angles is experimentally favorable for two reasons: First, the scattering cross section is larger for smaller angles. Second, less energy is lost by the scattered proton to the recoil of the alpha particle, and detection problems are simpler. It was desirable now to try to extend the prediction of polarization to the region of 18 MeV, the region of the proposed experiments. The only analysable proton-alpha cross section measurement above 9.5 MeV was due to the author [7]. The only phase shift analysis of that data was also due to the author and this was thought to be incorrect. It was necessary therefore to investigate the problem of extending the lower energy phase shifts from the region of 9.5 MeV to the region of 18 MeV.

If a thorough analysis of the data at 17.5 MeV is carried out, one must expect to find more than one set of phase shifts fitting the data. The reason for this is that the formula for the cross section in terms of the phase shifts is the squared magnitude of the amplitude function which itself involves the phase shifts as the arguments of trigonometric functions. Besides a possible ambiguity arising from the periodicity of trigonometric functions, there is the more serious problem that extraneous roots may appear due to the non linearity of the cross section formula. Thus unless one has additional information he will not know which set of roots at the higher energy corresponds to those known to apply at the lower energies.

One method that might be used to match the lower energy results to higher energy ones is to fit the lower energy ones with a model, such as an optical model, and to use the model to extrapolate the phase shifts to the higher energy. Such a procedure may seem risky. When optical models are used with heavier nuclei, the parameters used are found to vary with energy. In the present case the extrapolation required is over a region in which the energy almost doubles. In addition to this there is the opinion of many theorists that optical models should not be applied to very light nuclei. In spite of these difficulties, Gammel and Thaler have used a potential model for this purpose with some success [8].

Their model allows them not only to connect the low energy measurements with those at 17.5 MeV but also with those at 40 MeV. We shall comment on these results later but will first describe our own procedure for the extension of the lower energy phase shifts to the region of 18 MeV.

We use the fact that the phase shifts must be continuous functions of the energy. Then if several measurements of the cross section are made at energies intermediate to 9.5 MeV and 17.5 MeV and a phase shift analysis is made for each of these measurements, then one may follow the correct phase shifts up in energy using only the condition of continuity. Accordingly, a scattering chamber was set up to measure the cross section at a set of fixed angles at a number of energies between 11 and 18 MeV [9]. Figure 2 shows the proton helium scattering cross section at three energies. The vertical lines show the angles chosen for the new measurements. When these angles were chosen it was thought that they were a sufficient set for the purpose of phase shift determinations. This turned out to be a serious error in judgement. Apparently it is necessary to have measurements at still smaller angles to be able to determine the D wave phase shifts. If one smaller angle, say 20°, had been included, everything might have been all right. A least squares procedure was used to fit S and P phase shifts to the data. The fits obtained were very good, but when the phase shifts thus found were used to calculate the 17.5 MeV cross section it was found that the old data was not fitted in the small angle region. It was clear that the inclusion of D phase shifts was required at this energy

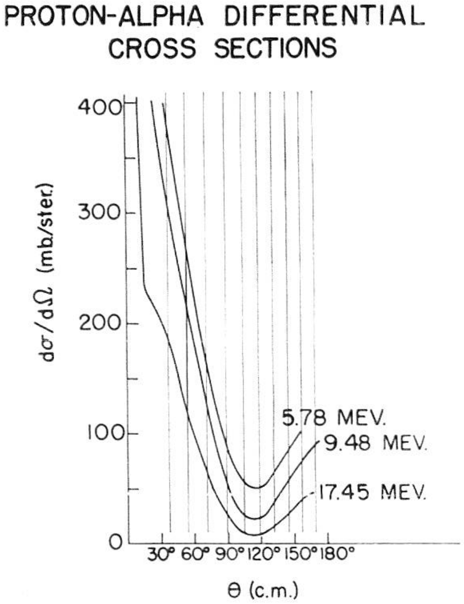

Figure 2

Proton alpha differential scattering cross section at three energies. Vertical lines show angles at which intermediate measurements were made (this was, of course, expected from the beginning) but that the new data was not sufficient to find them. A least squares procedure including D waves was also tried with the new data but this failed to converge in practically every case. The failure of the D wave procedure to converge was attributed to experimental error and to the lack of data at a smaller angle.

Figure 3 shows S and P phase shifts as a function of energy. Those below 10 MeV are due to previous work while those above are the results of the analyses made here in terms of S and P phase shifts only. The lines drawn have no theoretical significance but were drawn by eye to pass through the points. Values were taken from these lines however to calculate the expected polarization in this region. The question that arises now is what sort of confidence can one have in polarization calculations based on such values. If one observes the scatter of the points and considers the criterion used to draw the line, and if one considers the fact that D wave phase shifts which must be present in this energy range have been neglected, then he cannot have too much faith in the exact values calculated. It is highly probable, however, that in this energy region the D phase shifts are small, probably no greater than 10°. Thus while the calculations cannot be expected to provide a very accurate prediction of the polarization, they can nevertheless be used as a guide to the sort of thing that may be expected.

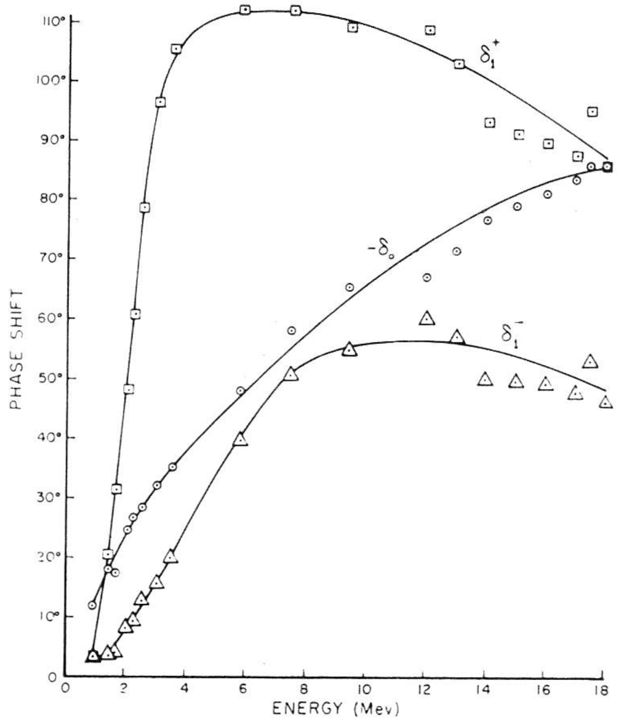

Figure 3

S and P phase shifts for proton alpha scattering as a function of energy

Figure 4 shows the angular distribution of polarization for 17.5 MeV proton-alpha scattering calculated with four sets of phase shifts. Curve 2 of the drawing was calculated using only the S and P phase shifts taken from the lines in figure 3. Curve 4 is calculated from GAMMEL and THALER's solution 5 [8]. This was their best fit to the 17.5 MeV data using S, P and D phase shifts. The remarkable agreement of these two calculations can only be regarded as fortuitous. Curve 3 was calculated from the phase shifts used to calculate the polarization chart of figure 1. They are closely related to one of GAMMEL and THALER's other solutions and were in fact chosen using some information received from them. Curve 1 was plotted from values read from GAMMEL and THALER's contour plot of polarization between 10 and 40 MeV [8]. This chart is based on the phase shifts calculated from their potential model which fits the data at 9.5, 17.5 and 40 MeV. The measurements shown are some of the measurements obtained by us which will be discussed a little later. They are not all at the same energy. Those at 30° and 45° were at about 17.5 MeV, but those at 65° and 115° were at about 15.5 MeV. Polarization at a particular angle does not vary very rapidly with energy in this region however so they still may be used to compare with the calculations. The interesting point to note here is the seeming superiority of GAMMEL and THALER's fit including only D waves (curve 4) to the results obtained from their potential mode (curve 1). While one of their purposes in choosing this model may have been to use it as an interpolation device, part of their motivation must have been to be able to account for the still higher order phase shifts which one feels

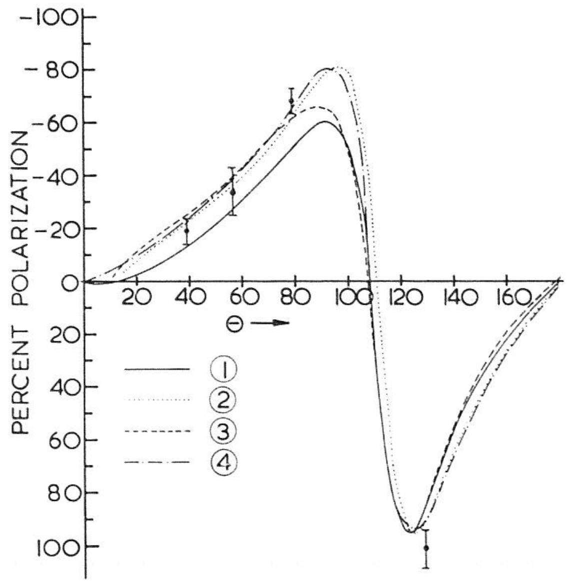

Figure 4

Angular distribution of polarization for 17.5 MeV proton alpha scattering. The various curves are identified in the text must be present. It is curious that when they try to account for these higher order partial waves that the results should be inferior to those when they are ignored. This difficulty introduced with their model also shows up in the scattering cross section. They refer to this as the forward scattering problem. Figure 5 shows the proton alpha differential cross section at 17.5 MeV in the region of the nuclear-coulomb interference. Here the cross section calculated from the model – the line in the drawing – shows a much more pronounced dip than the data will allow. Failure of the model to fit the data in this region again would indicate that the model in fact fails to account for the higher order phase shifts correctly. GAMMEL and THALER have discussed these shortcomings and have concluded that the polarization chart found by them may still be used as a guide, however the extent to which the accuracy of the figures may be trusted is not clear.

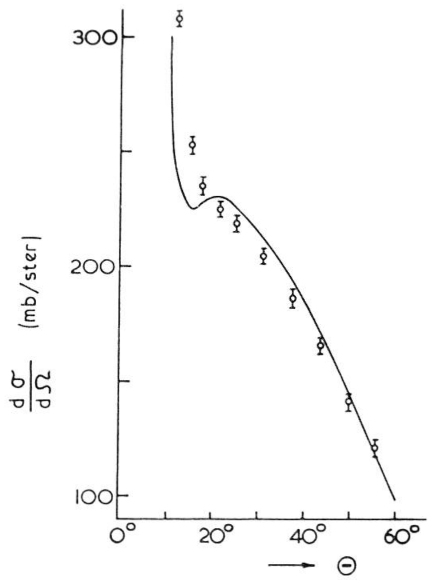

Figure 5

Proton alpha differential cross section at 17.5 MeV in the region of nuclear-coulomb interference. Theoretical curve is due to GAMMEL and THALER

We shall now return to the polarization measurements that were made around 17 MeV. The information that was found from the calculations concerning proton-alpha polarization was used to build a polarization analyzer based on the scattering of protons by helium at 65°. Figure 6 shows a drawing of the instrument. The first scattering target which was usually the material under investigation was placed about 2 inches in front of the first collimator. The second scattering was in helium gas at a pressure of about 7 atmospheres between the collimation vanes. The set up with the vanes to define the gas scattering geometry was chosen to get as high a counting rate as possible consistent with a reasonable efficiency and a reasonable energy resolution. Detection of the doubly scattered protons was by cesium iodide scintillation counters.

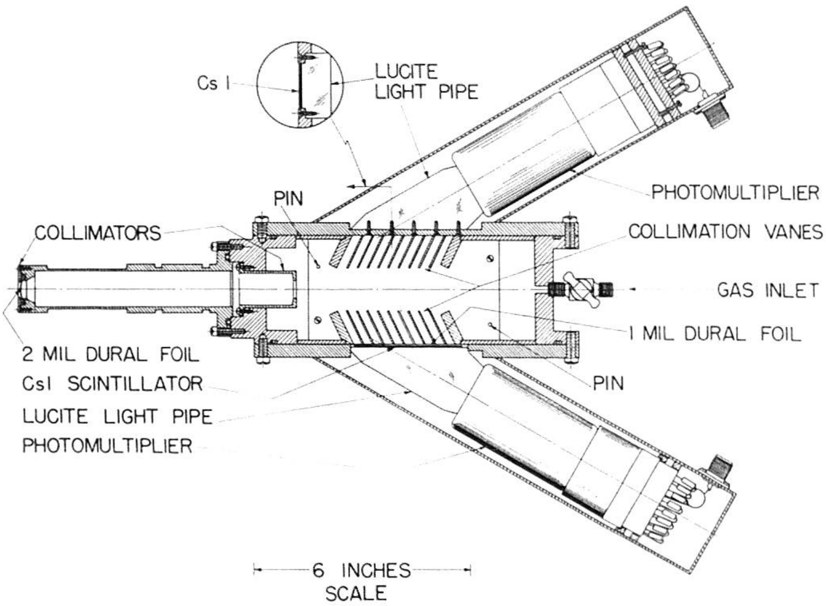

Figure 6

Helium polarization analyzer

Among the first measurements undertaken were those to calibrate the polarization analyzer and to check the calculated helium polarizations. It is possible to do a series of measurements involving three polarization events and to determine the magnitude of the polarization in each of the three. In our experiments the procedure was as follows: An experiment (experiment 1) was done in which an asymmetry A_1 was measured for two consecutive scatterings by carbon at 45°. Each of these scatterings is a separate event since the energy at the second target is lower than at the first. $A_1 = P_1 P_2$, where P_1 is the polarization of the first event and P_2 that of the second. Two more measurements were made. In these scattering by carbon at 45° was the first event and scattering by helium the second. The energy of protons incident on the helium target was adjusted to be the same for these two experiments by the use of foils. But in the first experiment of the two the energy at the carbon target was made the same as the energy incident on the first target in experiment 1, while in the second experiment it was made equal to the energy incident on the second target in experiment 1. The two asymmetries measured then are $A_2 = P_1 P_{He}$ and $A_3 = P_2 P_{He}$. The three asymmetries connect the three polarizations in three equations which may be solved for the polarizations. Calibration in this way is of the greatest value since it frees one of having to use the results of a theoretical calculation. Scattering by carbon at 45° was used in the calibration procedure because it was found early in our work that the polarization for this event was large and because the use of this event was experimentally simpler.

The results of measurements done to verify the predicted proton-alpha polarization have been shown in figure 4. The values obtained at 65° and 115° were found by using scattering by carbon at 45° as the first event and scattering by helium in the helium analyzer as the second. The 115° point was obtained by turning the collimation vanes of the analyzer around. The values obtained at 30° and 45° were found using a gas cell containing helium as the first scatterer. The helium analyzer was used for the second event.

The next series of measurements was to measure the angular distribution of polarization in the scattering of protons by carbon. The results of these measurements are shown in figure 7. Here the polarization measured for both the elastic scattering and the inelastic scattering with excitation of the 4.43 MeV level of carbon are shown. The lines have no significance and merely connect the points. The upper part of the figure shows the differential cross section for the two processes.

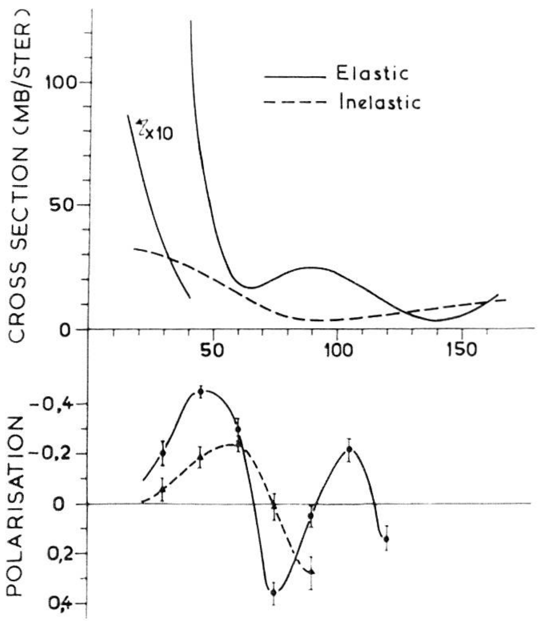

Figure 7

Angular distribution of polarization in the scattering of protons by carbon. Data are shown for elastic scattering and for inelastic scattering with 4.43 MeV excitation. Upper part of figure shows the associated differential cross sections

Blanpied continued measurements of this type. He has measured the angular distribution of proton polarization in scattering by magnesium, calcium, copper, silver and gold. The polarization patterns are oscillatory like those shown for carbon. He shows that the positions of the maxima and minima for all the measurements follow a systematic scheme. This is that they come at a certain set of values of $A^{1/3} \sin \theta/2$ which is proportional to the product of the nuclear radius and the momentum transfer in elastic scattering.

The third sort of experiment undertaken was an attempt to measure polarization in proton-proton scattering. This is an important measurement because it serves to differentiate between several sets of phase shifts that have been found to fit measured proton-proton cross sections. At the time when the measurement was first done there was very little theoretical guidance in the literature except that it should be small. A measurement was attempted scattering by hydrogen gas at 30° and analysing with the helium analyzer. The value obtained was $(1.2 \pm 2)\%$ which is consistent with zero.

BLANPIED has also remeasured the proton polarization but with an improved technique. The improvement regarded a method of eliminating the spurious asymmetries arising from the finite scattering geometry. The idea is as follows: It was found that protons scattered at around 45° from carbon and copper have a magnitude of polarization around 40% but the polarizations are of opposite sign. On the other hand the ratio of the slope of the cross section to the value of the cross section is about the same for these two targets at that angle. Now let carbon and copper be used alternately as the first target of a double scattering experiment and the material under investigation is used as the second target. The asymmetry arising from the effects of finite geometry, which is proportional to the slope to cross section ratio, is the same for either carbon or copper first target, but the asymmetry due to polarization changes sign with the alternation of targets. If then the asymmetry obtained with a carbon first target is subtracted from the asymmetry found with the copper, the finite geometry part drops out but the polarization part remains.

BLANPIED set up his experiment at 25° and used an energy of 16.2 MeV. The result obtained was $(0.6 \pm 0.5)\%$. While this value still may be said to be consistent with zero, it is a significant result for the problem of the proton-proton interaction.

REFERENCES

[1] K. W. BROCKMAN, Phys. Rev. *110*, 163 (1958).
[2] W. A. BLANPIED, Phys. Rev. *113*, 1099 (1959).
[3] W. A. BLANPIED, Phys. Rev. *116*, 738 (1959).
[4] C. L. CRITCHFIELD and D. C. DODDER, Phys. Rev. *76*, 602 (1949).
[5] M. HEUSINKVELD and G. FREIER, Phys. Rev. *85*, 80 (1952).
[6] D. C. DODDER and J. L. GAMMEL, Phys. Rev. *88*, 520 (1952).
[7] K. W. BROCKMAN, Phys. Rev. *102*, 391 (1956).
[8] J. L. GAMMEL and R. M. THALER, Phys. Rev. *109*, 2041 (1958).
[9] K. W. BROCKMAN, Phys. Rev. *108*, 1000 (1957).