

Figure 2 Analyzing powers for the  $^{12}\text{C}(\vec{p}, p')^{12}\text{C}$  reaction at 120 Mev (solid points) and 200 Mev (open points). States are labelled by  $E_x(J^\pi; T)$ . The curves are DWBA calculations at 120 MeV.

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2) J.R. Comfort, R.E. Segel, G.L. Moake, and D.W. Miller, to be published.

POLARIZATION AND SPIN-FLIP IN PROTON INELASTIC SCATTERING

T.A. Carey and J.M. Moss

Los Alamos National Laboratory, Los Alamos, New Mexico 87545

A.D. Bacher, D.W. Miller, H. Nann, C. Olmer, P. Schwandt, and E.J. Stephenson

Indiana University Cyclotron Facility, Bloomington, Indiana 47405

This report summarizes the first year's progress in a program which has as its general aim the detailed investigation of the spin-flip probability in proton inelastic scattering. To achieve this goal we have developed a flexible experimental system which permits concurrent measurement of all four partial differential cross sections  $\sigma_{ij}$  ( $i, j = +, -$ ) for scattering polarized protons from initial spin state  $i$  to final spin state  $j$ . With them we can then construct the total

differential cross section,  $\sigma$  ( $= \sigma_{++} + \sigma_{+-} + \sigma_{-+} + \sigma_{--}$ ), the analyzing power,  $A$  ( $\sigma A = \sigma_{++} + \sigma_{+-} - \sigma_{-+} - \sigma_{--}$ ), the final-state polarization,  $P$  ( $\sigma P = \sigma_{++} - \sigma_{+-} + \sigma_{-+} - \sigma_{--}$ ) and the spin-flip probability,  $S$  ( $\sigma S = \sigma_{+-} + \sigma_{-+}$ ). Whereas  $A$  is primarily sensitive to the average nucleon-nucleus spin-orbit field,  $S$  has been shown to be primarily dependent on the central and tensor spin-dependent terms of the effective nucleon-nucleon interaction<sup>1</sup>). In proton scattering these interactions

can lead to spin transfer accompanied by a flipping of the spin of the scattered particle. Of fundamental importance is the prediction that spin transfer generally leads to a large (near unity) value for  $S$ , and, conversely, in the absence of spin transfer the value obtained for  $S$  is small ( $\lesssim 0.1$  at small momentum transfer<sup>2</sup>). Thus measurements of  $S$  tend to complement those for  $A$  and should help to elucidate the relative effects of the various spin-dependent interactions that can connect the ground and excited states of nuclei. Indeed, our hope is that information on these observables will provide particularly stringent tests of the DWIA which, although generally successful, has suffered some notable failures in predicting  $\sigma$  and  $A$  for certain states strongly excited by  $\sim 150$  MeV protons.

An experimental determination of  $S$  for a particular excitation requires the scattering of a polarized beam from the target of interest followed by a precision measurement of the final-state polarization of the corresponding inelastically scattered particles. For this purpose, we have developed a polarimeter for use in the focal plane of the QDDM spectrograph whose design and operation is described in some detail in a later section of this report (Part 2: Technical Status of the Laboratory--Experimental Facilities Development).

In October 1980 we used this system to make the first measurements of  $S$  in the  $(p,p')$  reaction at intermediate energies. Spin-flip data were obtained for 150 MeV incident protons exciting the 12.71 MeV ( $1^+$ ,  $T=0$ ), 15.11 MeV ( $1^+$ ,  $T=1$ ) and 16.11 MeV ( $2^+$ ,  $T=1$ ) states of  $^{12}\text{C}$ . The results of a preliminary reduction of these data are displayed in Figure 1.

The aim of this first set of experiments was to provide some initial basis for an investigation into

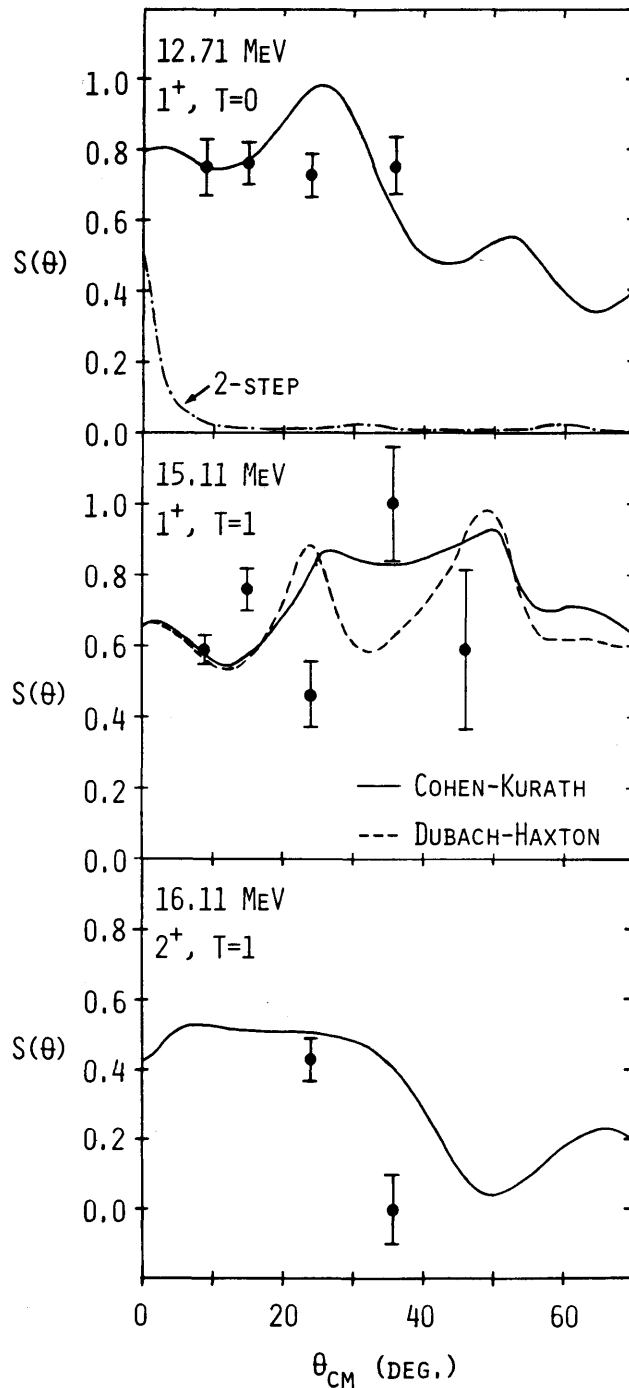


Figure 1. Angular distributions measured so far for the spin-flip probability in  $^{12}\text{C}(p,p')$ . The solid (dashed) curves are DWIA predictions for the Cohen-Kurath (Dubach-Haxton) wave functions and the latest Love-Franey effective interaction for  $\sim 150$  MeV protons.<sup>6</sup> The dash-dot curve represents a coupled-channels calculation employing collective-model form factors.

the sensitivities of  $S$  as an observable. Towards this end we are currently performing a series of calculations employing both the DWIA and the coupled-channels methods. Although these studies are still in their earliest phase we can make the following tentative observations (keeping in mind that a detailed comparison between theory and experiment must await further measurements and a consistent reduction of the data as a whole with a more systematic and quantitative approach to the estimation of uncertainties than has been used so far):

(i) 12.71 MeV ( $1^+$ ,  $T=0$ ) state -- The differential cross section and analyzing power for excitation of this state at IUCF energies have to date been very poorly described in the DWIA<sup>3</sup>). Speculation has held that this may be due to deficiencies in the IA effective interaction, contributions from multistep channels or a combination of these and other problems. Our surprising result is that  $S$  is large over the range where  $\theta_{cm} = 8^\circ-36^\circ$  with an angular distribution which is rather well described by the DWIA. Furthermore, coupled channels calculations show that a purely two-step inelastic excitation of this state proceeding through the 4.44 MeV ( $2^+$ ,  $T=0$ ) state yields  $S=0$ . The resolution of this apparent conflict is not presently obvious, and any clues which the new observable  $S$  may be providing about the excitation of this state will probably become clear only after more systematics have been gathered for  $\Delta T=0$  unnatural parity transitions.

(ii) 15.11 MeV ( $1^+$ ,  $T=1$ ) state ---Inelastic scattering to this state has recently attracted considerable interest as a potential test for the presence of precritical fluctuations in the nuclear

pionic field. These effects are expected to be most prominent at a momentum transfer (near  $2-3 m_\pi c$ ) for which both  $\sigma$  and  $A$  measurements with 120-800 MeV protons are not particularly well described by a simple excitation model<sup>3,4</sup>). We find that  $S$  for ( $p,p'$ ) transitions to this state is consistently large and is in qualitative agreement with DWIA predictions employing the Cohen-Kurath wave functions. However, given the sparseness of the current data it is obvious that we need additional measurements for  $\theta_{cm} > 25^\circ$  before any conclusions can be drawn concerning the importance of the minor differences between the Cohen-Kurath and the Dubach-Haxton wave functions which are so crucial to the interpretation of the corresponding ( $e,e'$ ) cross sections<sup>5</sup>).

In the meantime, calculations for the low momentum-transfer region have shown a remarkable sensitivity to the tensor component of the IA interaction. With reduced uncertainties for forward angle data one should be able to literally choose the "best" tensor interaction from the families which (iii) are currently available for  $\sim 150$  MeV protons. 16.11 MeV ( $2^+$ ,  $T=1$ ) state ---Both  $\Delta S=0$  and  $\Delta S=1$  transfer are allowed in the excitation of this state. Since only the  $\Delta S=1$  amplitude produces substantial spin-flip, measurements of  $S$  should be quite sensitive to the  $\Delta S=1/\Delta S=0$  ratio predicted by any assumed wave functions. We have found  $S$  to be large ( $\approx 0.45$ ) near the peak of the cross section for the excitation of this state; this constitutes the first direct evidence for the importance of  $\Delta S=1$  transfer in this natural-parity transition.

This result is in good agreement with DWIA calculations using Cohen-Kurath wave functions while p-shell wave functions, which admit no  $\Delta S=1$  strength, produce substantial disagreement with the data.

In conclusion, the goal of this program is the exploration of the spin-flip probability as an additional probe of nuclear structure and reaction mechanisms in (p,p'). Since this is the first such endeavor at intermediate energies we will in the future seek to broaden our data base in terms of the types of excitations studied. Strong and weak transitions involving both  $\Delta T=0$  and  $\Delta T=1$  transfer for relatively pure proton and neutron promotions to both low and high spin states (particularly stretched configurations) need to be probed at a variety of momentum transfers. Also, we hope to investigate the prediction that intermediate-energy spin-flip measurements can be used to elucidate the  $\Delta J \neq 0$  contributions to elastic scattering from odd mass nuclides. This should yield information on the diagonal matrix elements of the spin-dependent operators which is complementary to that

contained in the transverse form factors derived from elastic electron scattering. Finally, we will consider the potential utility that a broad-range, second-generation focal-plane polarimeter might have in searches for new magnetic modes of excitation which lie in a background of more strongly excited electric multipoles.

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#### 135 MeV PROTON SCATTERING FROM $^{13}\text{C}$

S.F. Collins, B.M. Spicer, G.G. Shute and V.C. Officer  
University of Melbourne, Parkville, Victoria, Australia 3052

D.W. Devins, D.L. Friesel and W.P. Jones  
Indiana University Cyclotron Facility, Bloomington, Indiana 47405

Spectra from the scattering of 135 MeV protons from  $^{13}\text{C}$  have been measured at angles from  $8^\circ$  to  $80^\circ$  in the laboratory, using the QDDM spectrograph. Four momentum bites were used at each angle, covering the region from 0 to 24 MeV in excitation. A preliminary report on the spectra in the 2 higher energy bites was given in last year's report.<sup>1)</sup>

Peak areas have been extracted using the code GENFIT<sup>2)</sup> at IUCF and GAUSSFIT2 at Melbourne. The target used had a thickness of  $9.5 \text{ mg/cm}^2$  and was isotopically enriched to 92%  $^{13}\text{C}$ . Angular distributions from the impurity  $^{12}\text{C}(p,p')$  reaction for the prominent states agreed well with those measured previously by this group. Runs on different targets