

## ELASTIC AND INELASTIC SCATTERING

SPIN-FLIP AND P-A FROM THE  $^{12}\text{C}(\text{p}_{\text{pol}}, \text{p}'\gamma)^{12}\text{C}$  REACTION AT 150 MeV

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For several years quantitative information on the spin-dependent components of the nucleon-nucleon force has been sought in a variety of proton scattering experiments. Two techniques have been used in these studies: polarization transfer measurements have been made using proton polarimetry in the focal plane of magnetic spectrometers, and  $(\text{p}, \text{p}'\gamma)$  angular correlations have been measured in the "spin-flip" geometry. Until recently beam energies for these studies have generally been limited to less than about 50 MeV. At these low energies the spin dependence of the nucleon-nucleon interaction is largely obscured by spin-orbit distortions in the entrance and exit channels, and little quantitative information about the force has been learned from these experiments.

For many states with large gamma-ray decay strengths the  $(\text{p}, \text{p}'\gamma)$  reaction is ideally suited for study of spin transfer at intermediate energies. Recently,<sup>1</sup> we initiated an experimental investigation of the spin-flip probability (S) and polarization-analyzing power difference (P-A) following inelastic scattering of polarized protons at 150 MeV. In this work the state of interest was the  $1^+$  state at 15.11 MeV in  $^{12}\text{C}$ . The observables S and P-A were measured by observing a coincidence between the

inelastically scattered proton and the de-excitation gamma-ray. The QDDM magnetic spectrometer was used to detect the scattered protons, and the gamma-rays were observed in a 10-in.-diameter by 12-in. long shielded NaI crystal mounted in a direction normal to the scattering plane, i.e., above the target chamber, which yields the "out-of-plane" correlation. The proton spin-flip probability for each beam orientation is determined by the observed coincidence rate. Differences between the coincidence yield for spin-up versus spin-down incident beams result from differences between the polarization and analyzing power for the reaction. For elastic scattering  $P = A$  due to the time-reversal invariance of the strong interaction. But P need not equal A for inelastic excitations.

Our current data for the spin-flip asymmetry are shown in Fig. 1. This observable is defined as

$$\frac{\Delta S}{S} = - \frac{(P-A)}{2S}$$

and is sensitive only to components of the interaction which can flip the nucleon spin, as shown in the figure. These data complement the low-q data taken at the same energy, and extend it to  $q = 425 \text{ MeV}/c$ . The

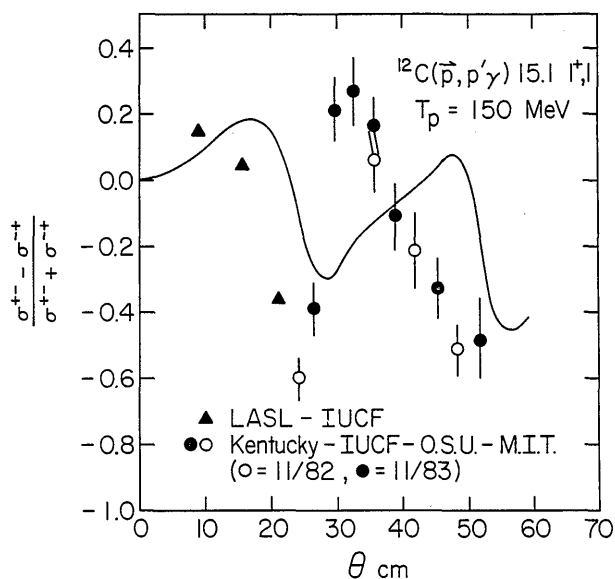


Figure 1. Spin-flip asymmetry for inelastic proton excitation of the  $1^+, 1$  state in  $^{12}\text{C}$  at  $E_p = 150$  MeV. The solid curve shows the result of a DWIA calculation using the Love-Franey Interaction and Cohen-Kurath wave functions.

curve is a DWIA calculation using the Love-Franey interaction and Cohen-Kurath wave functions. A more recent calculation (not shown) using the Paris interaction achieves a much superior fit to the data.

Recently, Love,<sup>2</sup> and Love and Comfort<sup>3</sup> have investigated dynamical sources of  $P \neq A$  beyond the effect of the  $Q$ -value. Their calculations indicate that for inelastic excitations, non-zero  $P$ - $A$  values can arise from non-local couplings of the spin-dependent components of the  $N$ - $N$  interaction. These couplings between nucleons are of the form of a current coupled with the nucleon spin. This source of  $P \neq A$  is shown to be relevant to excitation of the  $1^+, 1$  state in  $^{12}\text{C}$  because a major component of the structure of that state has quantum numbers which strongly couple to this term in the interaction, that is with transferred quantum numbers  $LSJ = 111$ . It has been pointed out<sup>4</sup> that because of this sensitivity, measurements of  $P$ - $A$  for this state can be used to determine a combination

of density-matrix elements which are not otherwise derivable from, for example, transverse electroexcitation.

When using a NaI detector the enormous background of neutrons in the vicinity of the target necessitates running the coincidence experiments at low beam currents so that the rate of background events in the gamma-ray detector is limited to about 300,000 per second. The corresponding rate of real coincidences is then at worst about 10 events per hour. Nevertheless, in these running conditions the true-to-accidental ( $T:A$ ) coincidence ratio achieved with NaI is 10:1. For the spin-flip and  $P$ - $A$  measurements this low true event rate is acceptable because the  $T:A$  ratio is so good, and because only one gamma-ray angle need be observed.

In June, 1983, we borrowed a  $3''\phi \times 3''$  BGO detector from the Harshaw Chemical Co. for 24 hours of tests with a 150-MeV proton beam at IUCF. In these first studies we were able to process BGO linear signals at the 2-MeV level--far below the approximately 8-MeV lower limit imposed in NaI by internal activation. This enhanced capability of BGO detectors will enable coincidence studies to extend to low-lying bound states in a wide range of nuclei. And, while the energy resolution for BGO is not as good as NaI, the missing mass in this type of coincidence reaction is determined solely in the proton arm. In addition, we have observed that a favorable coincidence  $T:A$  ratio is maintained even when the energy definition window of gamma-ray events is considerably relaxed, as would necessarily be the case if BGO detectors were used instead of NaI.

1) M.A. Kovash et al., Bull. Am. Phys. Soc. 28, 690 (1983); M.A. Kovash, et al., IUCF Scientific and Technical Report 1982, p. 1.

- 2) W.G. Love, International Symposium on Light Ion Reaction Mechanisms, Osaka, Japan (1983).  
3) W.G. Love and J.R. Comfort, private communication.

- 4) T.A. Carey et al., Phys. Rev. Lett. 49, 266 (1982).

# ENERGY DEPENDENCE OF INELASTIC PROTON SCATTERING TO ONE-PARTICLE ONE-HOLE STATES IN $^{28}\text{Si}$

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The study of intermediate-energy proton inelastic scattering to one-particle one-hole states is a particularly useful technique for examining selected features of the effective nucleon-nucleon interaction. The structural simplicity of these excited states permits the possible separation of effects due to nuclear structure and those resulting from the reaction mechanism. The present work has concentrated on a study of the energy dependence of proton inelastic scattering for three high-spin, particle-hole states in  $^{28}\text{Si}$ : the  $5^-$ ,  $T=0$  state at 9.70 MeV, the  $6^-$ ,  $T=0$  state at 11.58 MeV, and the  $6^-$ ,  $T=1$  state at 14.35 MeV. Cross-section and analyzing-power measurements for these excitations have been measured at incident proton energies of 80, 100, 134, and 180 MeV, and the data are tabulated in Appendix II, p. 171. The results of this completed study have been recently published;<sup>1</sup> some of the major conclusions of this work are presented here.

A region of the inelastic scattering spectrum measured at 180 MeV is displayed in Fig. 1. Also displayed is a spectrum measured<sup>2</sup> at the same momentum transfer (near the maximum of the cross-section distribution) for an incident proton energy of 800 MeV. The  $6^-$  states are the dominant peaks in the spectrum over the indicated range of excitation energy for the data at 180 MeV, whereas these states are only barely

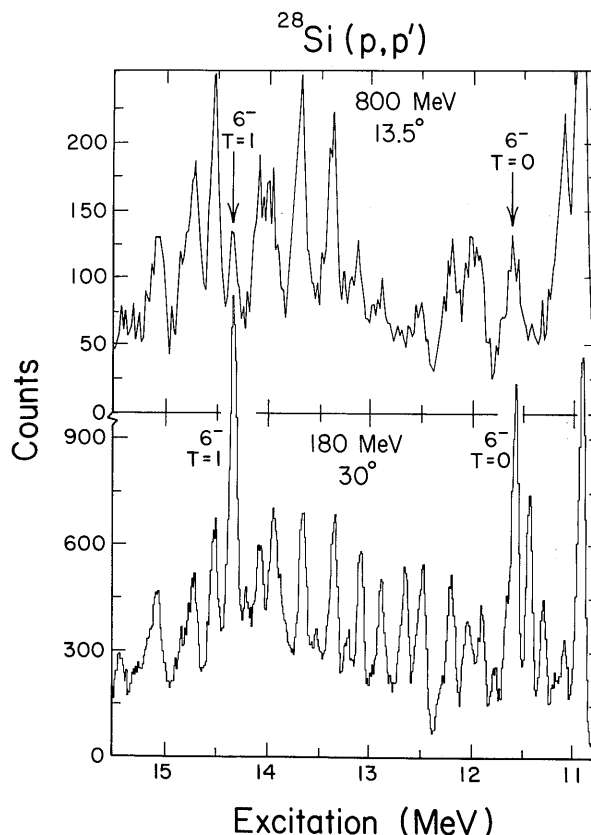


Figure 1. Inelastic proton spectra for the scattering of 180-MeV (bottom) and 800-MeV (top) protons from silicon at similar values of momentum transfer. The 800-MeV data are from Ref. 2.

visible at 800 MeV. This behavior is a consequence of the significant energy dependence of the central, spin-independent term in the effective interaction,