

SPIN TRANSFER MEASUREMENTS FOR (p,n) REACTIONS AT INTERMEDIATE ENERGY

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We have previously reported¹ the results of the first spin transfer measurements for (p,n) reactions at intermediate energy (160 MeV). These initial measurements demonstrated the feasibility of using hydrocarbon scintillator (NE102 in this case) as a neutron polarization analyzer and confirmed the expected spin transfer signature for Gamow-Teller (GT) type transitions ($\Delta J^\pi=1^+$, $\Delta L=0$). Additional measurements carried out in March 1984 as a continuation of IUCF experiment 186 have yielded several significant new results. These are:

1. spin transfer angular distributions for ${}^6\text{Li}$, ${}^{13}\text{C}$, and ${}^{15}\text{N}$ at $E_p=160$ MeV,
2. high quality spin transfer data for ${}^{90}\text{Zr}(p,n)$ at 160 MeV and $\theta=0^\circ$, for excitations up to $E_x=50$ MeV,
3. experimental calibration of the absolute magnitude and energy dependence of the polarimeter analyzing power for neutron energies $117 \text{ MeV} < E_n < 160 \text{ MeV}$. (New results from a January, 1985 run have now extended this calibrated range to 77 MeV.)

Angular distributions of the transverse spin transfer coefficient D_{NN} can provide information about

the low momentum transfer strength of the tensor interaction. Some measured values of $D_{NN}(\theta)$ for ${}^{13}\text{C}(p,n){}^{13}\text{N}(\text{g.s.})$ and ${}^6\text{Li}(p,n){}^6\text{Be}(\text{g.s.})$ at $E_p=160$ MeV are shown in Fig. 1. Also shown in this figure are the results of distorted-waves impulse approximation (DWIA) calculations employing the 140-MeV t-matrix interaction of Love and Franey² and the lp-shell wave functions of Cohen and Kurath.³ The data seem to favor

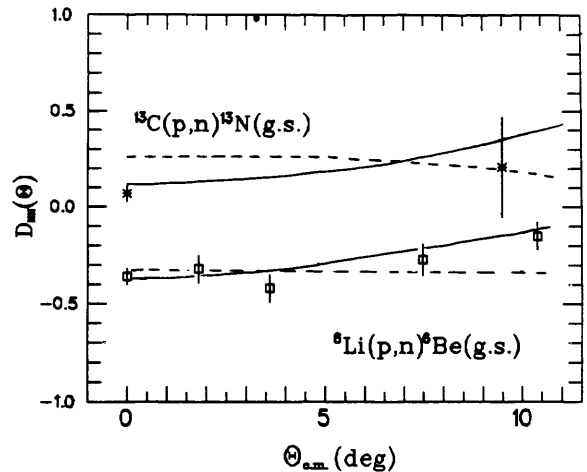


Figure 1. Transverse spin transfer angular distributions at $E_p=160$ MeV. The solid lines are the result of DWIA calculations employing central, spin-orbit, and tensor components in the interaction. The dashed lines correspond to calculations employing a central interaction only.

the calculations employing the full (central + spin-orbit + tensor) interaction (solid lines), and are in poorer agreement with calculations done with a central interaction only (dashed lines).

At zero degrees the effect of the tensor interaction is minimized and simple predictions can be made for the value of $D_{NN}(0^\circ)$ to be expected for a particular multipolarity.⁴ For GT transitions, the expected value is $D_{NN}(0^\circ) = -1/3$, and an empirical average for pure GT transitions (i.e., $\Delta J^\pi=1^+$, $\Delta L=0$ transitions with no interfering background) at $E_p=160$ MeV is $D_{NN}(0^\circ) = -0.33 \pm 0.05$. The uncertainty in this average value represents real deviations from the nominal value as well as statistical and systematic uncertainty in the measurements. For other multiplicities, the values expected for $\Delta S=1$ transitions are

$$D_{NN}(0^\circ) = 0 \quad \Delta J = \Delta L$$

$$< -1/3 \quad \Delta J = \Delta L \pm 1$$

and for $\Delta S = 0$ transitions

$$D_{NN}(0^\circ) = 1.$$

Note that the value of $-1/3$ for GT transitions is the least negative D_{NN} expected for an unnatural parity ($\Delta J \neq \Delta L$) excitation.

The most interesting aspects of the $^{90}\text{Zr}(p,n)$ data are illustrated in Fig. 2. The spin-flip cross section $\sigma_{S_{NN}}$ (top), non-spin-flip cross section $\sigma(1-S_{NN})$ (middle), and D_{NN} (bottom) are presented as functions of excitation energy in 1 MeV energy bins. Transitions that are pure spin-flip ($D_{NN} = -1$) or pure non-spin-flip ($D_{NN}=1$) will appear in only one of the two cross section spectra. The obvious example here is the isobaric analog state (IAS) transition that stands out prominently at $E_x=5$ MeV in the non-spin-flip spectrum and in the D_{NN} spectrum. The continuum region in the spin flip spectrum is rather flat and featureless,

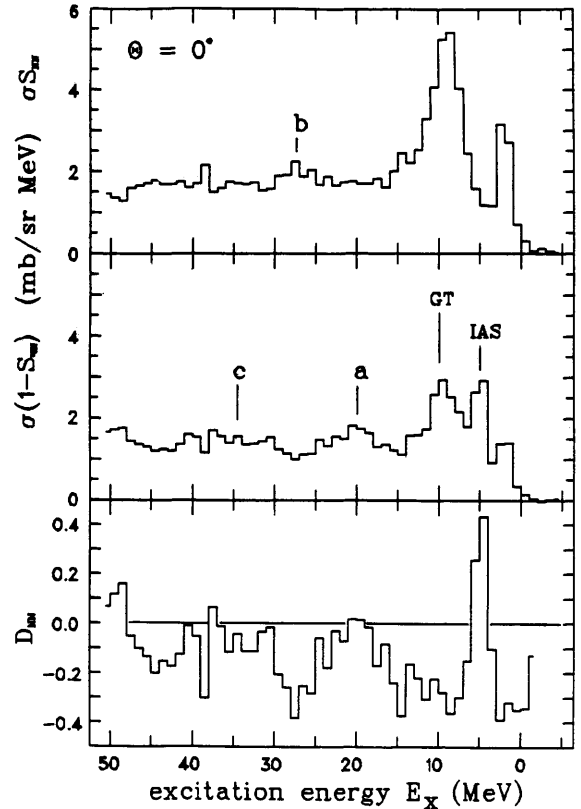


Figure 2. Spin flip cross section (top), non-spin-flip cross section (middle), and $D_{NN}(0^\circ)$ (bottom) for $^{90}\text{Zr}(p,n)$ at $\theta=0^\circ$ and $E_p=160$ MeV.

while two wide "bumps" appear in the non-spin-flip spectrum at $E_x=20$ MeV ("a") and $E_x=35$ MeV ("c"). The appearance of these features in the non-spin-flip spectrum but not in the spin-flip spectrum suggests the excitation of $\Delta S=0$ strength. The values of D_{NN} for these regions confirm a substantial amount of natural parity strength. The bump at $E_x=20$ MeV is at the same excitation energy as a resonance previously identified⁵ as $\Delta L=1$. The measured value of D_{NN} thus suggests that a large fraction of the strength is $\Delta J^\pi=1^-$ (and possibly 2^+ as well). It is interesting to note that the possible $\Delta S=0$ bump at $E_x=35$ MeV ("c") is at the excitation energy predicted for the 0^+ isovector monopole (IVM) resonance⁶ and has approximately the

width (≈ 12 MeV) expected for the IVM. Other natural parity excitations, such as 3^- or 2^+ , could also contribute in this region, however. New D_{NN} measurements at 120 MeV, where $\Delta S=0$ excitations should be enhanced by a factor of ≈ 1.75 relative to 160 MeV, may help clarify interpretation of the strength in this region. Finally, note that the region marked as "b" in the spin-flip spectrum corresponds to a relatively large negative value of D_{NN} . Possible candidates for explaining the data in this region are 1^+ ($\Delta L=2$) or 0^- excitations.⁷

The polarimeter used to make the above measurements has been previously described.¹ It consists of two parallel planes of scintillator oriented perpendicular to the incident neutron flux. A crucial requirement for the analysis of the high excitation $^{90}\text{Zr}(p,n)$ data was the calibration of the polarimeter analyzing power as a function of energy. The calibration was achieved by observing neutrons produced by the $0^+ \rightarrow 0^+ \text{ } ^{14}\text{C}(p,n)^{14}\text{N}(2.31\text{-MeV})$ IAS reaction at $E_p=120$ MeV and 160 MeV. The polarization of such neutrons at zero degrees is equal to the polarization of the incident proton beam. The results of the 120 MeV and 160 MeV calibrations are shown in Fig. 3. The effective polarimeter analyzing power A_{eff} is smaller by a factor of 0.83 ± 0.08 from the values obtained by averaging the free n-p analyzing power over the acceptance of the polarimeter. This reduction is mainly the result of contaminant contributions from $^{12}\text{C}(n,n'\alpha)$ reactions.

An important parameter related to polarimeter performance is the effective area a_ϵ , that is, the product of the double-scattering efficiency and the area of the front face of the analyzer. This quantity, when multiplied by the integrated neutron flux I_n (neutrons/cm²), gives the number of useful double-

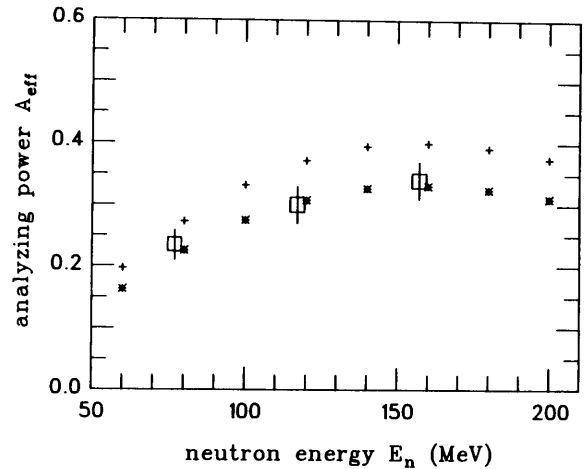


Figure 3. The measured effective analyzing power A_{eff} of the polarimeter. The crosses represent calculations of the n-p analyzing power averaged over the acceptance of the polarimeter. The asterisks are these same calculations normalized to the data.

scattered-neutron events. For the present polarimeter, with an interplane separation of 0.85 m, the effective area is $a_\epsilon = (4590 \text{ cm}^2)(5.0 \pm 0.5) \times 10^{-4} = 2.3 \pm 0.2 \text{ cm}^2$ for 120 MeV neutrons. This is achieved with a total scintillator volume of only 137,700 cm³.

Another important quantity is the figure-of-merit FOM, defined as

$$\text{FOM} = a_\epsilon A_{\text{eff}}^2.$$

The statistical uncertainty in a measurement of the neutron polarization is given by

$$\delta p_n \approx (I_n \text{FOM})^{-1/2}.$$

For the present polarimeter, $\text{FOM} = 0.21 \pm 0.02 \text{ cm}^2$ for 120 MeV neutrons.

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MEASUREMENTS OF GAMOW-TELLER STRENGTH DISTRIBUTIONS IN MASSES 13 AND 15

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Allowed Fermi and Gamow-Teller beta decay transition rates provide a special class of nuclear model information because of the simple relationship between the model description of the nucleus and the transition process. The Fermi (F) operator changes only the isospin projection of a nucleon. The Gamow-Teller (GT) operator changes the projections of both isospin and spin. The transition rate between mirror states is the incoherent sum of the rates for the Fermi and Gamow-Teller components. All of the Fermi strength appears in the mirror state transition, but due to the spin-orbit interaction, the GT strength is distributed between the spin-orbit pair states, and only a fraction of the total GT strength is contained in the mirror state transition.

In mass 13 the ratio of measured¹ and calculated² GT strengths for the $1/2^- \rightarrow 1/2^-$ mirror transition is 0.66. This ratio is consistent with the "typical" GT quenching factor. However, the calculated B(GT) value for the strongest transition,² that from the ground state of ^{13}C to the $3/2^-$, 3.51-MeV level in ^{13}N , is B(GT)=2.38, while the value deduced from our (p,n) measurements³ is B(GT)=0.85±0.03, a discrepancy of nearly a factor of three. The calculated B(GT) summed over all levels is 3.95.

For mass 15, if we hold only to the restriction that the model space be limited to the p-shell, unlike the situation in mass 13, the total GT strength and the distribution of strength between the p $1/2$ and p $3/2$ hole states are independent of the spin-orbit splitting