SPIN TRANSFER IN $(\vec{p},\vec{n})$ REACTIONS

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The (p,n) reaction at intermediate energies has become an important probe of spin-excitation ($\Delta S = 1$) strength in nuclei. The circumstance responsible for this development is the dominance at energies larger than about 50 MeV of the isovector spin-flip component $V_{\sigma\tau}$ over the non-spin-flip component V_{τ}.[1,2] This dominance causes $\Delta S = 1$ excitations to be favored over $\Delta S = 0$ excitations by a ratio of 13:1 at 200 MeV.[1]

Identification of spin-flip excitation strength has been made largely on the basis of the observed energy dependence and shape of differential-cross-section angular distributions. Despite the apparently successful application of such inferential evidence, some important ambiguities remain in trying to characterize features observed in (p,n) spectra. In spectra obtained with medium and heavy-mass nuclei the excited states and giant resonances ride on a large continuum background. The large widths (several MeV) of the resonances make it difficult to separate these excitations from the underlying continuum. The problem is further complicated by the changing shape of the continuum as a function of angle.

While it is not possible to gain a complete understanding of the giant resonances and the continuum by using differential cross sections alone, measurements of spin-dependent quantities should help to sort things out. For angles larger than 0°, measurements of the analyzing power appear to provide valuable information despite the lack of a unique signature for $\Delta S = 1$ and $\Delta S = 0$ excitations.[3] A quantity that does uniquely characterize $\Delta S = 1$ and $\Delta S = 0$ transitions is the transverse-polarization-transfer coefficient $D_{NN}(\theta)$. At $\theta = 0°$ this quantity is simply the ratio of outgoing to incoming projectile polarization: $D_{NN}(0°) = p_f/p_i$. Non-spin-flip transitions such as $0^+ \to 0^+$ IAS reactions will have $D_{NN}(0°) = 1$, while $0^+ \to 1^+$ spin-flip excitations will have the distinctly different value $D_{NN}(0°) \simeq -1/3$.

Direct measurement of the spin transfer in (p,n) reactions at intermediate energy should help to establish the magnitude and nature of the continuum and answer the question of whether or not it contains previously undetected GT strength. Such studies will be aided by the eventual measurement of all relevant spin-transfer coefficients, i.e., the spin transfer in the longitudinal (L) and sideways (S) directions in addition to the transverse (N) direction. These directions are defined in terms of the incident and outgoing projectile momenta as:

$$\hat{L} = \hat{k}_i,\ \hat{L}' = \hat{k}_f,\ \hat{N} = \hat{N}' = \hat{k}_i \times \hat{k}_f,$$
$$\hat{S} = \hat{N} \times \hat{L},\ \text{and}\ \hat{S}' = \hat{N}' \times \hat{L}'.$$

The differential cross section for nucleon inelastic scattering may be represented as[4,5]

$$\sigma(\theta) = \sigma_L(\theta) + \sigma_T(\theta), \quad (1)$$

where the longitudinal (L) and transverse (T) cross sections are proportional to the longitudinal $\vec{\sigma}\cdot\vec{q}$ and transverse $\vec{\sigma}\times\vec{q}$ spin transition densities and may be expressed in terms of the unpolarized differential cross section $\sigma(\theta)$ and three of the five non-zero spin transfer coefficients as[4]

$$\sigma_L = (\sigma/4)(1 - D_{NN'} + D_{SS'} - D_{LL'}), \quad (2a)$$

and

$$\sigma_T = (\sigma/4)(3 + D_{NN'} - D_{SS'} + D_{LL'}). \quad (2b)$$

This separation into longitudinal and transverse components is interesting because the longitudinal component is untested by (π,π') and (e,e') reactions and therefore represents valuable new information.

Spin transfer measurements are useful not only for the nuclear structure information they provide but are crucial for obtaining a better understanding of the effective interaction that mediates intermediate-energy inelastic nucleon-nucleus scattering. Transitions for which nuclear structure or transition strength information is available from other probes are useful tools for studying the effective interaction and the applicability of the impulse approximation at intermediate energies. Nuclear-medium effects that modify the free nucleon-nucleon interaction are more susceptible to understanding when information in addition to cross sections is available.[6] The importance of such effects is clearly evident in the comparison of the $V_{\sigma\tau}/V_\tau$ ratio determined from (p,n) measurements and that predicted from free nucleon-nucleon interaction studies.[1]

We have initiated a program of $(\vec{p},\vec{n})$ spin transfer measurements employing the neutron polarimeter configuration illustrated in Fig. 1. The polarimeter consists of six standard large-volume (15 × 15 × 100 cm, NE102) neutron detectors arranged in three stacks of two detectors. The detector stacks are oriented perpendicular to the incident neutron flux and are

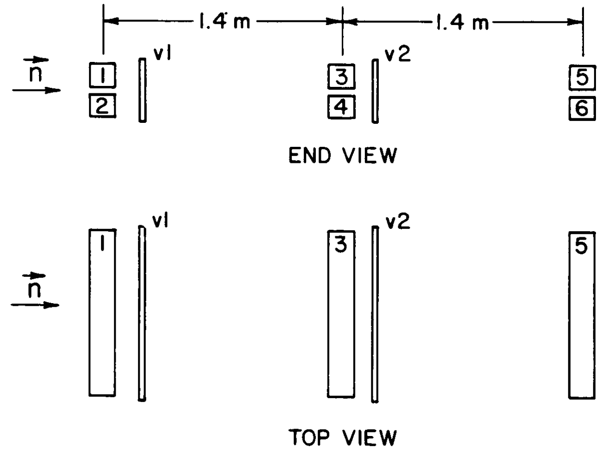

Figure 1. Schematic diagram of the neutron polarimeter to be used for spin transfer meaurements at IUCF. The neutron flux is incident from the left. The veto scintillators v1 and v2 eliminate false coincidences caused by forward-scattered protons from $^1H(n,p)n$ reactions.

separated by a distance of about 1.4 m. The two forward-most detectors serve as active analyzers, while the middle two detectors can be either analyzers or polarimeter "arms." Time signals derived from both ends of each detector are combined to yield position and time-of-flight information for each event. A valid event consists of a coincidence between any two detectors that are not in the same stack. The event is characterized as a "left" scatter or a "right" scatter by utilizing the position information from each detector.

The primary analyzing reaction is $^1H(n,n)^1H$, which has an average analyzing power of $A(\theta) \simeq 0.3$ for $10° < \theta_{lab} < 40°$ and $E_p = 160$ MeV. The inclusive reaction $^{12}C(n,n'x)$ has a similar analyzing power[7] over the range $6° < \theta_{lab} < 25°$. These two reactions in the analyzer may be discriminated by use of the time-of-flight between the analyzing detector and the trailing "arm" detector and the pulse height of the event in the analyzing detector.

The effective analyzing power and instrumental asymmetry of the polarimeter are determined by calibration runs with the incident proton beam in different polarization states. In terms of the yield of neutrons scattered to the left (Y_L) and to the right (Y_R), the neutron polarization p_n is given by

$$p_n = \frac{1}{A} \frac{Y_L - (\varepsilon_L/\varepsilon_R)Y_R}{Y_L + (\varepsilon_L/\varepsilon_R)Y_R} , \qquad (3)$$

where $\varepsilon_L(\varepsilon_R)$ is the relative efficiency for detection of left(right)-scattered neutrons and A is the effective analyzing power. The polarimeter constants A and $(\varepsilon_L/\varepsilon_R)$ are determined by measuring the left and right yields of neutrons produced by the $0^+ \rightarrow 0^+$ $^{14}C(p,n)^{14}N(2.31\ MeV)$ reaction for two different proton-beam polarization states. The neutrons produced by this reaction have the same polarization as the incident protons.

The polarimeter configuration described here was tested during a run in July 1982. This run immediately followed the installation of the new polarized ion source and was consequently hampered by substandard polarized beam quality ($I_p \simeq 10$ nA, $|p_y| < 0.6$) during the shakedown period. Despite these difficulties data were obtained for $(\vec{p},\vec{n})$ reactions on targets of ^{13}C, ^{14}C, and ^{90}Zr. The runs were too short to obtain the statistics required for extracting values for $D_{NN}(0°)$, but the overall polarimeter performance was judged satisfactory. Energy resolution of approximately 1 MeV was obtained (for $E_n \simeq 160$ MeV and a flight path of 60 m) with good discrimination between left and right scattering. Some results from this initial test are shown in Figs. 2-4. A summary of "typical" quantities desired for $(\vec{p},\vec{n})$ measurements with this polarimeter is presented in Table I.

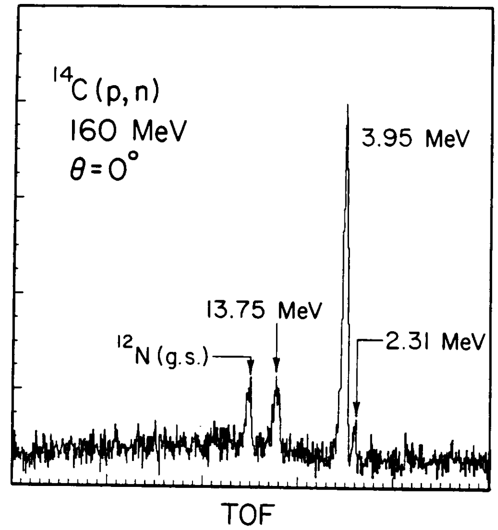

Figure 2. Time-of-flight spectrum obtained for the $^{14}C(p,n)$ reaction at 160 MeV. Neutrons from the transition to the 2.31-MeV state in ^{14}N have the same polarization as the incident proton beam and are thus useful for calibrating the polarimeter. The energy resolution in this singles spectrum is approximately 1 MeV.

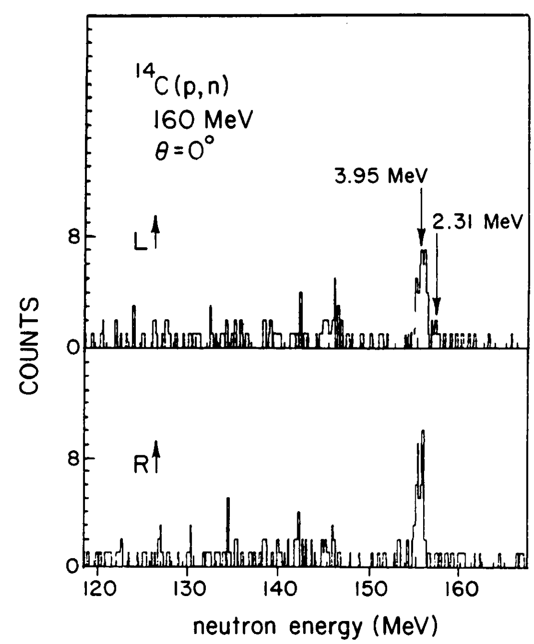

Figure 3. Coincidence energy spectra obtained for the $^{13}C(p,n)$ reaction with a proton beam in the spin-up orientation. The spectra shown were obtained in approximately 6.5 min with a beam current of 12 nA.

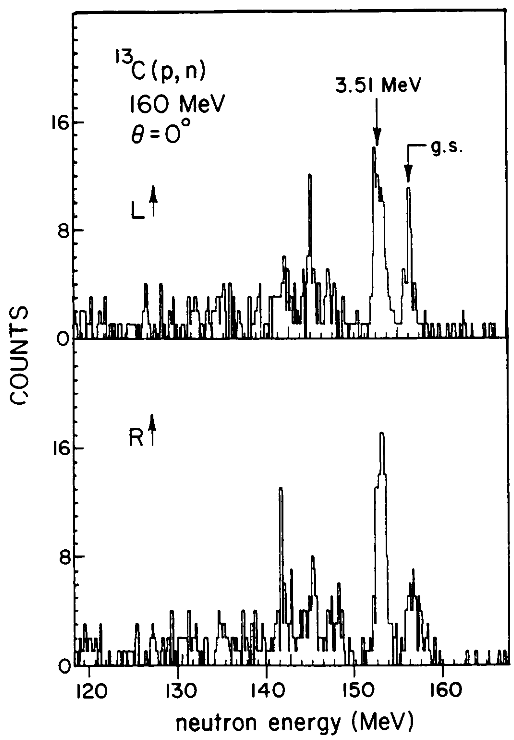

Figure 4. Coincidence energy spectra obtained for the $^{14}C(p,n)$ reaction with a proton beam in the spin-up orientation. The spectra shown were obtained in approximately 7.5 min with a beam current of 12 nA.

TABLE I. Typical parameters for $(\vec{p},\vec{n})$ measurements at IUCF.

Primary scattering	
Beam current	50 nA
Polarization	0.75
Target thickness	30-200 mg/cm^2
Flight path	60 m
Energy resolution	1 MeV
Δθ horizontal	1°
Secondary scattering	
Polarimeter efficiency	(2-8) x 10^{-4}
Effective analyzing power	0.3
Δθ horizontal	35°
Angular resolution	4°
Position resolution	5 cm

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