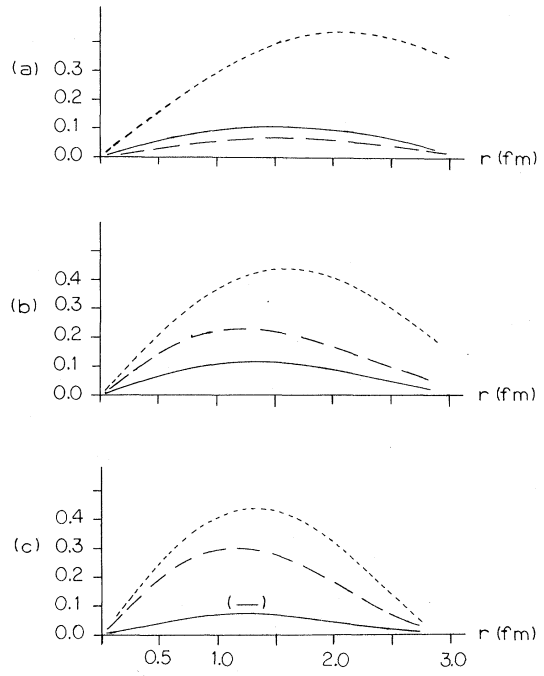

FIG. 2. $\Delta_{l=1}{}^{(1)}$ and $j_1(kr)$ as function of pion kinetic energies. The labels for the curves are the same as for their counterparts in Fig. 1.

Gordon equation

$$[\omega^2(\vec{k}) - 2\omega(\vec{k})W_{\omega(\vec{k})} - h_\pi{}^2]\,|\chi_{\vec{k}}\rangle^+ = 0 \qquad (23)$$

will yield identical results if

$$W_{\omega(\vec{k})} = \left[\frac{\omega(\vec{k}) + h_\pi}{2\omega(\vec{k})}\right] U_{\omega(\vec{k})}$$

$$= U_{\omega(\vec{k})} + \left[\frac{h_\pi - \omega(\vec{k})}{2\omega(\vec{k})}\right] U_{\omega(\vec{k})}. \qquad (24)$$

The differences which we have been discussing all arise from the neglect of the second term on the right-hand side of Eq. (24).

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Retarded Isoscalar $M2$ Strength Observed in the Reaction $^{16}O(p_{pol}, p_{pol}')^{16}O(2^-, 8.88\ MeV)$ at E_p=40 MeV

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Measurement of the spin-flip probability in the reaction $^{10}O(p_{pol}, p_{pol}')^{16}O(2^-, 8.88\ MeV)$ at E_p = 40 MeV yields values that are significantly smaller than those predicted by microscopic distorted-wave Born-approximation calculations. This is interpreted as direct evidence for the dominance of multistep processes in this reaction. Analysis of the data in terms of the spin-flip cross section (spin-flip probability times the differential cross section) yields an isoscalar $M2$ strength for the 2^- which is significantly smaller than that predicted by random-phase–approximation wave functions.

The observation of magnetic multipole transitions is of fundamental interest in nuclear physics. Electromagnetic probes have to date provided the bulk of information on these transitions.[1] Because of the predominantly isovector nature of magnetic multipole fields, the known strong transitions are primarily of isovector character. Inelastic proton scattering with spin transfer ($\Delta s = 1$) offers an alternative method of studying configurations with large magnetic multipole strength. The analogy between magnetic transitions and inelastic scattering (including charge exchange) with $\Delta s = 1$ has been noted before[2,3]; we therefore employ the term "magnetic" to refer to both cases (the radial forms of the inelastic scattering and magnetic operations are not necessarily

the same). Inelastic scattering with spin transfer has the advantage that isovector magnetic transitions may be excited with roughly equal strength.

In the past, the (p,p') reaction has been employed to study isoscalar magnetic transitions in the excitation of $T=0$ unnatural-parity states.[4] The assumption of a single-step process leads to the selection rules, $\Delta t=0$ and $\Delta s=1$; hence a measurement of the differential cross section is sufficient to infer the transition strength. We present evidence based on a study of the spin-flip (SF) probability in the (p,p') excitation of the 2^- (8.88 MeV, $T=0$) state of ^{16}O, that the single-step assumption is grossly in error at $E_p=40$ MeV. Analysis of these data and previously reported[5] SF data for the reaction ^{12}C$(p,p')^{12}$C(12.71 MeV, 1^+, $T=0$) forces re-examination of the isoscalar magnetic transition strengths associated with these important states. At the same time a means of resolving the conflict between previously reported[5,6] SF data and conventional central-plus-tensor effective interactions becomes apparent.

The present method for measuring the SF probability $[S(\theta)]$ utilizes a high-efficiency, high-resolution polarimeter to obtain the final polarization in a (p,p') reaction induced by a polarized beam. The polarimeter is located in the focal plane of an Enge split-pole spectrograph whose magnetic field is adjusted to place the reaction group of interest on the polarimeter target. Details regarding the alignment and operation of the polarimeter are given in Moss, Brown, and Cornelius.[7] Briefly, the quantity which is measured, the final polarization p_f, is related to the initial beam polarization p_i by

$$p_f=[P(\theta)+p_iK_y{}'(\theta)]/[1+p_iA(\theta)], \quad (1)$$

where $K_y{}'(\theta)$ is the transverse polarization transfer coefficient, and $P(\theta)$ and $A(\theta)$ are, respectively, the polarization function and the analyzing power. Measurements of p_f with initial spin up (+) and down (-) may be combined to yield

$$K_y{}'(\theta)=[(p_f{}^+-p_f{}^-)+A(\theta)(p_i{}^+p_f{}^+-p_i{}^-p_f{}^-)]/(p_i{}^+-p_i{}^-). \quad (2)$$

The quantity $K_y{}'(\theta)$ ranges between $+1$ and -1 and is related to $S(\theta)$ by $K_y{}'(\theta)=1-2S(\theta)$.

The requirement of a small beam-spot size in the present experiment made the use of a gas target impractical. A series of ~40-mg/cm^2 Mylar targets were used in the measurements at $\theta_{lab}=20°$ and 35°; however, because of decomposition in the beam, the oxygen content of these targets decreased steadily, resulting in a loss by a factor of ~3 in count rate after 2 hours. A much more satisfactory solution was found by using a thin liquid water target. A thin flat cell was constructed consisting of two tightly stretched Kapton plastic windows (~1 mg/cm^2 thick) glued onto a thin aluminum frame. Water was then injected into the space between the windows with a hypodermic needle. The water cell was sealed and placed inside a second, larger Kapton cell which was mounted in the scattering chamber. The second cell was maintained at atmospheric pressure to insure that the water cell remained perfectly flat and of uniform thickness when the scattering chamber was evacuated. The equivalent thickness of ^{16}O was 40 mg/cm^2. The data were taken in runs lasting from 2 to 6 hours. The beam polarization (70%) was continuously monitored with a thin ^{12}C target polarimeter located upstream from the spectrograph.

The most interesting feature of the SF probability is its close relationship to spin transfer in inelastic scattering. It is easily demonstrated by distorted-wave Born-approximation (DWBA) calculations (discussed below) that the dominance of spin transfer leads inevitably to a large SF probability. In view of this, the data of Fig. 1

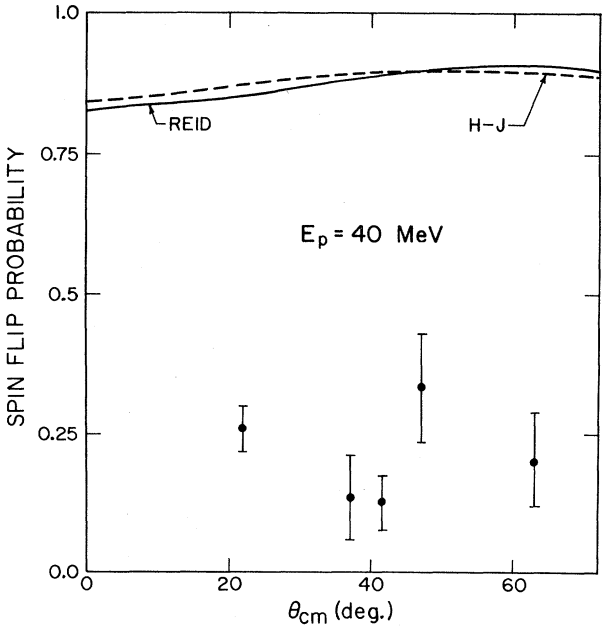

FIG. 1. Spin-flip probability for the 2^- (8.88 MeV) in ^{16}O. The curves are DWBA calculations using residual interactions derived from the Reid and Hamada-Johnston (H-J) potentials.

for the reaction $^{16}O(p_{pol}, p_{pol}')^{16}O(2^-, 8.88\ MeV)$ are most surprising. For this unnatural-parity transition where $\Delta s = 1$ is required in a single-step excitation, the experimental values are near 25%. In order to gain more insight into these data, we have performed antisymmetrized DWBA calculations with the code DWBA-70.[8] Effective nucleon-nucleon (N-N) interactions were used which have been derived from the Hamada-Johnston (H-J) and Reid potentials.[9] The random-phase–approximation (RPA) wave functions of Gillet and Vinh Mau[10] were employed for the $0^+ \rightarrow 2^-$ transition. Optical-potential parameters were taken from Austin.[11] Spin-flip probabilities substantially larger than experiment are obtained in both cases (Fig. 1). The large predicted values of $S(\theta)$ cannot be reduced to the level of the experimental data even by drastic modification of the optical potential, the wave function, or the effective interaction. We believe therefore that the small percentage of SF seen here can be interpreted only one way: The dominant mechanism in the (p, p') excitation of the 2^- at $E_p = 40$ MeV cannot be direct spin transfer. Whatever the nature of the more complex mechanism, it need not involve spin transfer. In fact, on general grounds, since the spin independent N-N interaction is much stronger than the spin-dependent interaction, spin transfer and hence SF should be a minor contribution to multistep reactions. With the assumption of no SF from the multistep process, there is no interference between it and the direct process, and the experimentally observed SF probability will be

$$S_{expt}(\theta) = \frac{\sigma_s(\theta)}{\sigma_s(\theta) + \sigma_m(\theta)} S_s(\theta), \qquad (3)$$

where s stands for spin transfer and m for multistep. The experimental value of $S(\theta)$ is thus reduced by a factor which depends on the relative contribution of multistep reactions. Now the absolute value of $S_{expt}(\theta)$ means very little when compared to a DWBA calculation for $S_s(\theta)$ only.

Viewed in this light, discrepancies between theoretical and experimental SF probabilities,[5,6] in the reactions $^{11}B(p_{pol}, n_{a\ pol})^{11}C$ [where $K_y{}^{y'}(\theta) = 1 - 2S(\theta)$ was calculated] and $^{12}C(p_{pol}, p_{pol}')^{12}C$ $(0^+ \rightarrow 1^+, T=0)$ may be due to contributions from other reaction mechanisms rather than indications of an inadequate residual interaction. This alternative is particularly attractive in the $^{11}B(p_{pol}, n_{pol})^{11}C$ case[6] where too much SF was predicted by a residual interaction which yielded too little cross section.

Even with the presence of more complicated mechanisms one can compare theoretical and experimental SF cross sections $\sigma_{SF}(\theta)$ since from Eq. (3)

$$\sigma_{SF}(\theta) = [\sigma_s(\theta) + \sigma_m(\theta)] S_{expt}(\theta) \simeq \sigma_s(\theta)$$

and the quantities on the right-hand side may be calculated. This should represent the true isoscalar $M2$ strength in the (p, p') reaction in the limit that $S_m(\theta) \rightarrow 0$. We have taken differential cross sections from the literature[11,12] in order to produce $\sigma_{SF}(\theta)$ for the 2^- $(T=0)$ state in ^{16}O and the 1^+ $(T=0)$ state in ^{12}C. [The reaction $^{11}B(p_{pol}, n_{pol})^{11}C$ involves a different isospin transfer and will be treated in a later publication.] These are compared to DWBA calculations in Fig. 2. The Cohen-Kurath (CK) wave functions[13] were used for ^{12}C, and optical-potential parameters were taken from Watson, Singh, and Segel[14] and Kolata and Galonsky.[15] The agreement in ^{12}C is acceptable particularly for the N-N interaction from the H-J potential. However, the SF cross section for the 2^- state in ^{16}O is overpredicted by a factor of ~4 to 5 at forward angles. The ^{12}C fit can be regarded as a calibration of the $\Delta T = 0$ N-N interaction, so that the large discrepancy in ^{16}O indicates a serious deficiency in the RPA description of the $0^+ \rightarrow 2^-$ transition. To be more quantitative in the comparison we have calculated "single-particle" transitions for the ^{12}C and ^{16}O cases using, respectivley, $(p_{3/2}{}^{-1} p_{1/2})_{1^+}{}^{T=0}$ and $(p_{1/2}{}^{-1} d_{5/2})_{2^-}{}^{T=0}$ configurations in conjunction with the H-J effective interaction. When these calculations are normalized to those using the more complicated wave functions, one finds a strength of 0.18 single-particle units (SPU) for the 1^+ $(T=0)$ of ^{12}C. This is in very good agreement with the $B(M1) = 0.19$ SPU derived from the CK wave functions for the $M1$ decay of the 15.11-MeV 1^+ state of ^{12}C. Apart from isospin, the wave functions of the two 1^+ states are very similar. In ^{16}O, on the other hand, the RPA wave functions give 0.64 SPU compared to only 0.12 SPU observed experimentally. This large overestimate of the isoscalar $M2$ strength in the $0^+ \rightarrow 2^-$ transition cannot be remedied easily. It is known, for example, that the spectroscopic factors for the $^{15}N(^3He, d)^{16}O(2^-)$ and $^{17}O(p, d)^{16}O(2^-)$ are well reproduced by Tamm-Dancoff–approximation (TDA) calculations[16] that yield spectroscopic coefficients for the $0^+ \rightarrow 2^-$ transition which are very close to those used here. If one arbitrarily reduces the $p_{1/2}{}^{-1} d_{5/2}$ amplitude and increases the $p_{3/2}{}^{-1} d_{5/2}$ amplitude to reduce the $M2$ rate,

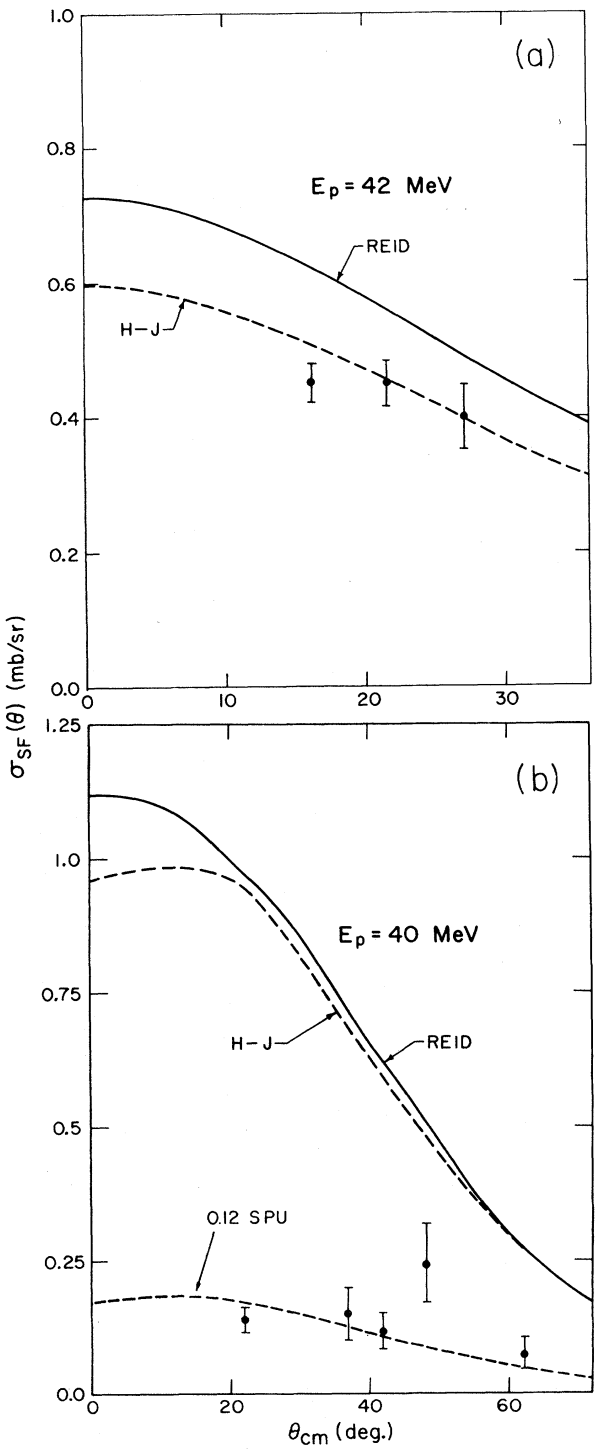

FIG. 2. Spin-flip cross section of the 12.71-MeV (1^+, $T=0$) state of ^{12}C and the 8.88-MeV (2^-, $T=0$) state of ^{16}O. The curves are DWBA calculations using residual interactions derived from the Reid and Hamada-Johnston (H-J) potentials. The lower dashed curve in (b) is a DWBA calculation with the H-J interaction and a pure $(p_{1/2}^{-1}\, d_{5/2})_{2^-}^{T=0}$ configuration. The magnitude of this curve was adjusted to fit the data.

one loses very quickly the agreement with the single-nucleon spectroscopic factors. At present we do not see an easy way out of this dilemma.

In summary, comparison of experimental and theoretical SF probabilities for the (p,p') excitation of the 8.88-MeV 2^- state of ^{16}O at $E_p = 40$ MeV leads to the conclusion that multistep processes account for most of the excitation strength of this state. The multistep process may involve the collective 6.13-MeV 3^- state or possibly the virtual excitation of natural-pairty giant resonances.[12,17] The isoscalar $M2$ strength can still be obtained, however, by forming the SF differential cross section. Comparison of DWBA calculations of this quantity to the experimental values for the 12.71-MeV 1^+ state of ^{12}C and the 8.88-MeV 2^- state of ^{16}O reveals good agreement in the former case and a large disagreement in the latter, where the DWBA calculation of $\sigma_{SF}(\theta)$ is ~5 times larger than the data. The discrepancy appears to be due to an inadequacy of the RPA description of the 0^+-to-2^- $M2$ transition strength.

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Properties of the Intermediate Structure in ^{71}As

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The spins and parities of the five reported $l=0$, $J^\pi=\frac{1}{2}^+$ substructures nested within the broad $l=0$ analog resonance in ^{71}As at $E_p=5.05$ MeV have been measured. Three of the five substructures were determined as having J^π different from $\frac{1}{2}^+$, casting doubt on the interpretation of this resonance as an example of intermediate structure.

In a Letter, Temmer *et al.*[1] reported an unusual and, to date, unique type of intermediate structure which had widths *below* the rank of analog states but *larger* than the ultimate fine structure. Experimentally, they observed five substructures superimposed on a broad analog state near 5.05 MeV bombarding energy in ^{70}Ge+p elastic scattering, with four of these substructures identified as having the $l=0$, $J^\pi=\frac{1}{2}^+$ character of the broad analog state. This, coupled with the fact that the substructures were correlated in several inelastic proton channels, led these authors to propose these substructures as possible candidates for "hallway" states coupled to the broad analog or doorway states. Today, these remain as one of only three[2,3] reported candidates for intermediate structure in charged-particle scattering and hence are of unusual interest. Baudinet-Robinet and Mahaux[4] appled statistical criteria to unpublished high-resolution cross-section data and determined that at least three of these substructures were statistically significant. Hence, these states can legitimately be considered to be candidates for an intermediate-structure interpretation. However, the substructures must have the same J^π assignment as the doorway (analog) state for such an interpretation and to date these assignments are based only on the analysis of cross-section data. Because of the importance of the J^π assignments here, we undertook in the present work to measure the spins of the structures in a more conclusive way than has been done previously. Our measurements consisted of $(p,p'\gamma)$ angular correlation measurements over the structures most prominent in the inelastic proton channel leading to the 2^+ first excited state of ^{70}Ge and, additionally, analyzing-power measurements for the elastic proton channel over the entire energy region of interest. Our results show that three of the substructures have spins other than $\frac{1}{2}^+$, excluding the possibility that they are members of the intermediate-structure state.

The $(p,p'\gamma)$ angular correlations were measured in the Goldfarb-Seyler geometry[5] at several energies over the two most prominent structures observed in the p_1 channel at 5.04 and 5.14 MeV. As in our previous utilizations of this technique[6] we did not observe any appreciable strength for the decay of a $\frac{1}{2}^+$ state through a 2^+ decay channel, probably because of barrier-penetrability suppression. The ratio of the A_4 to A_0 polynomial coefficients, obtained in fits to the angular correlation data, rose from zero off resonance to a value of ~ 0.4 on the resonance peaks. These results indicated $J \geq \frac{5}{2}$ for both of these resonances. Details of these measurements will be published elsewhere.

Glashausser *et al.*[2] reported on the evidence for intermediate structure in the inelastic scattering of polarized protons from ^{26}Mg and ^{27}Al. They point out that the lack of selectivity in the (p,p') reaction mechanism makes it difficult to observe definitely nonstatistical peaks in cross-section excitation functions. However, they noted that the analyzing power (A_y) is a sensitive indicator of coherent structure. For this experiment on the structure in ^{71}As, analyzing-power measurements should be particularly conclusive in determining the spins of the substructures since the analyzing power over a $J^\pi=\frac{1}{2}^+$ resonance is identically zero. Consequently, values of A_y different from zero within the structure should provide evidence for spins other than $\frac{1}{2}^+$.

The elastic-scattering experiments were carried out using protons from the Ohio State University polarized-ion source.[7] The analyzing

