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Polarization Transfer in Inelastic Scattering
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Invited talk at the 5th International Symposium on
Polarization Phenomena in Nuclear Physics

ABSTRACT

Polarization transfer experiments are now feasible for inelastic scattering experiments on complex nuclei. Experiments thus far have dealt with the spin-flip probability; this observable is sensitive to the action of spin-spin and tensor forces in inelastic scattering. Spin-flip probabilities at $E \sim 40$ MeV in isoscalar transitions in ^{12}C (12.71 MeV) and ^{16}O (8.89 MeV) show considerable deviation from DWBA-shell model predictions; this indicates evidence for more complex reaction mechanisms. Experiments at intermediate energies will soon be possible and will yield data of much higher precision than is possible at lower ($E < 100$ MeV) energies. These experiments hold exciting promise in such areas as nuclear critical opalescence.

INTRODUCTION

A glance through the contributed papers in nuclear structure and reactions at this conference reveals that a majority of them deal with measurements of analyzing powers. These observables are relatively easy to obtain with present day polarized beams since they require only measurement of single intensities for various beam polarization states. Polarization transfer observables (triple scattering parameters), on the other hand, usually require not only a polarized beam, but analysis of the final polarization state as well; until recently such experiments were limited to light nuclear systems where poor resolutions and (or) low efficiencies could be tolerated.

What I hope to convince you of in the course of this talk is that polarization transfer can lead to a new and interesting class of physics, quite different from that obtained from analyzing powers, and that these experiments can now be performed with sufficiently high efficiency and resolution for nuclear structure studies. The particular observable which I will focus on is the transverse spin-flip (SF) probability, S , in inelastic scattering. In terms of the Wolfenstein parameter, D , the SF probability is $S = 1/2(1 - D)$.

Measurement of S can be made in certain restricted cases without resorting to polarization analysis^{1,2}, but in general, one needs a polarimeter with both good resolution and high efficiency. These requirements can be met by coupling a polarimeter to a magnetic spectrograph as is shown schematically in Fig. 1. The properties of three such polarimeters constructed for different proton energy ranges are given in Table 1. It is obviously a great

TABLE I - POLARIMETER CHARACTERISTICS

<u>Polarimeter</u>	<u>Energy Range</u> (MeV)	<u>Efficiency</u>	<u>Analyzing Power</u>
Texas A&M	30	4×10^{-5}	0.42
Indiana	150	2×10^{-3}	0.4
LAMPF-HRS	500-800	7×10^{-2}	0.25

advantage to use medium-energy protons where the longer range can be exploited to produce a very high efficiency double-scattering target. The Texas A&M and Indiana polarimeters, which resemble the schematic of Fig. 1, are designed for measuring S for one final momentum at a time. The LAMPF-HRS polarimeter, on the other hand, utilizes an array of multi-wire drift chambers together with a software reconstruction of double-scattered particle trajectories to give polarization analysis for a broad range of momenta in the focal plane of the high-resolution spectrometer (HRS).

The unique features of S as an observable arise from its close connection to spin transfer, s, and to the action of spin-dependent forces in inelastic scattering. One can show in the Eikonal approximation³ for central spin-dependent forces that the SF probability associated with a given ℓ , s, and j transfer, $S_{\ell sj}$, is:

Fig. 1. Schematic focal-plane polarimeter.

$$\begin{array}{lll}
 S_{lsj} = \frac{3l+1}{2(2j+1)} & j = l + 1 & \\
 S_{lsj} = \frac{3l+2}{2(2j+1)} & j = l - 1 & s = 1 \\
 S_{lsj} = 1/2 & j = l & \\
 S_{lsj} = 0 & & s = 0
 \end{array}$$

More relativistic calculations of S over a wide range of energies show that S is large ($S \geq 0.5$) only when $s = 1$ and that $S \sim 0$ in the absence of spin transfer. As examples one might expect $S \sim 0$ for a collective $0^+ \rightarrow 2^+$ excitation in the (p,p') reaction, while for a $0^+ \rightarrow 1^+$ transition, one should see $S \geq 0.5$. As a final note DWBA calculations of S show a remarkable insensitivity to spin-orbit distortion from the proton-nucleus optical potential; this is in contrast to the large sensitivity exhibited by vector analyzing powers at energies below 100 MeV.

SPIN FLIP AT LOWER ENERGIES

Rather than review all of the cases studied thus far (see Refs. 3 and 4) I want to concentrate on a few which illustrate the nature of S as an observable and its potential at intermediate energies where much more precise data should be easily obtainable.

The $1^+ \rightarrow 0^+$ ($T=1$, 3.56 MeV) transition in ${}^6\text{Li}$ is a well-studied isovector "spin flip" transition. In the (p,p') reaction excitation may proceed by $lsj = 011$ and 211 transfer. Figure 2 shows measurements of S at two angles at $E_p = 32$ MeV. In accordance with our simple arguments, S is large in this transition where, due to angular momentum selection rules, spin transfer must occur in a single-step reaction. A DWBA calculation employing the Cohen and Kurath⁵ (CK) wave function in conjunction with a N-N interaction derived from the Reid potential⁶ gives a good account of the data. One might be tempted to infer deep meaning from the success of the calculation, however over the entire angular range shown in Fig. 2 the predicted value of S is very close to the value $S = 2/3$ expected from pure $lsj = 011$ transfer. Thus any combination of interactions and wave functions which do not suppress this matrix element will give similar results. In this case then, at the level of precision of the present data, S only confirms what was known before: this reaction proceeds by single step spin transfer.

Fig. 2. Spin-flip probability for ${}^6\text{Li}(3.56 \text{ MeV})$

All is not so simple though even when the data have fairly large error bars. Figures 3 and 4 show the SF probability and cross section data for the 12.71 MeV, 1^+ , $T=0$ state of ${}^{12}\text{C}$ at $E_p = 42 \text{ MeV}$. The best calculation utilizing the CK wave functions together with the Reid interaction substantially overestimates S . This is not a simple problem of optical potential ambiguities, since a plane wave calculation yields results scarcely distinguishable from the DWBA result. Removing the tensor part of the effective interaction seems to help; but now the magnitude of $d\sigma/d\Omega$ is no longer well described.

A key to where the solution to this discrepancy may lie is suggested by the spectacular failure of conventional theory in the case of the 8.39 MeV, 2^- , $T=0$ state of ${}^{16}\text{O}$. Here DWBA calculations (Fig. 5) with either the Gillet-Vinh Mau or single-particle wave functions (not shown) yield large values of S (as they must since $s=1$). Experimental SF probabilities in contrast hover around 20-25%. Our interpretation of this dilemma is that the main excitation strength for this state at $E_p = 40 \text{ MeV}$ cannot be single step $s = 1$ transfer. Other possibilities include multiple $s = 0$ excitation proceeding through the 6.13 MeV, 3^- , $T=0$ state and perhaps other states, sequential transfer, i.e. $(p,d)(d,p)$, and the excitation of giant resonances. Now it is plausible that, whatever the more complex mechanism, (there may of

Fig. 3. Spin-flip probability for ^{12}C (12.71 MeV)

Fig. 4. Differential cross section for ^{12}C (12.71 MeV).

Fig. 5. Spin-flip probability for ^{16}O (3.33 MeV).

course be several) it does not produce much spin flip. This follows from the general observation that spin dependent effective forces are substantially weaker than spin independent ones. In the limit that the SF probability associated with the more complex mechanism is zero, one can write for the experimentally observed value S_{exp} as:

$$S_{\text{exp}} = S \frac{(d\sigma/d\Omega)}{(d\sigma/d\Omega)_{\text{exp}}}$$

where $(d\sigma/d\Omega)$ and S are the quantities associated with pure spin transfer. It is still possible to calculate the product $(d\sigma/d\Omega)_{\text{SF}} \equiv S_{\text{exp}} (d\sigma/d\Omega)_{\text{exp}} = S(d\sigma/d\Omega)$. The comparison of experiment and calculation based on the $(d\sigma/d\Omega)_{\text{SF}}$ for the 2^- state is shown in Fig. 6 for both the Reid and Hamada-Johnston (HJ) effective interactions. There is obviously still a large discrepancy. Now, however, the culprit would seem to be the Gillet-Vinh Mau wave function. This

Fig. 6. Spin-flip cross section for ^{16}O (8.88 MeV)

is perhaps not surprising since isoscalar "magnetic" transition densities have not previously been subjected to much scrutiny. The isoscalar coupling in transverse magnetic electron scattering, for example, is very weak and is therefore sensitive to completely different coherences in wave functions than is isoscalar spin flip in inelastic proton scattering.

SPIN FLIP AT INTERMEDIATE ENERGIES

Polarization transfer at intermediate energies is a very exciting prospect for two reasons: First the theoretical tools which may be applied are more powerful than at lower energies, and second, polarimeters with orders of magnitude higher scattering efficiencies can be constructed thereby yielding data of much higher quality than is possible at lower energies. Work has just begun at Indiana, and only a small amount of preliminary data is available. This fall extensive programs of polarization transfer are scheduled both at LAMPF and Indiana. At LAMPF experiments will measure not only S but other triple scattering parameters as well.

As an illustration of the type of investigation currently envisaged, consider the question of nuclear critical opalescence. This phenomenon, first suggested by Ericson and Delorme¹⁰, is a type of precritical enhancement of the nuclear pion field which is expected to occur if nuclei are sufficiently close to the critical density for pion condensation. Toki and Weise¹¹ have

made explicit calculations for critical opalescence in the $^{12}\text{C}(p,p')^{12}\text{C}$ (15.11 MeV, 1^+ , $T=1$) reaction at 800 MeV. The precritical enhancement is seen as a substantial increase in the cross section for momentum transfers in the range $q = 2$ to $3 m_\pi$. A discrepancy between impulse approximation calculations and experimental differential cross section data for the 15.11 MeV state in this range of momentum transfer has been seen at $E_p = 122, 185$ and 800 MeV. The lower energy cross sections from Ref. 12 are shown in Fig. 7. The obvious question to ask is, "Does this discrepancy imply an enhancement of the spin dependent N-N effective interaction, i.e. critical opalescence, or is the reaction mechanism poorly described in this region of q ?" To see why a measurement of S may provide the answer, assume that the SF probability is measured in the region of critical opalescence and that the result is $S \neq 0$. This would be a strong indication of the dominance of a more complex reaction mechanism having nothing to do with enhanced spin transfer (this argument was used in the case of the 2^- in ^{16}O). A large SF probability would not immediately verify the idea of critical opalescence, but at least it would strengthen the evidence in favor of it.

The coming year will see a vast increase in both the quality and quantity of polarization transfer data on complex nuclei. There are already many important questions to be addressed by these experiments, and undoubtedly new surprises and questions will arise when the experimental results are known. At the next International Polarization Conference it would not be surprising to see a much larger number of contributions in the area of polarization transfer experiments.

Fig. 7. ^{12}C (15.11 MeV) data from Indiana. The solid curves are distorted-wave impulse approximation calculations.

References

1. F. H. Schmidt et al., Nucl. Phys. 52, 353 (1964).
2. R. H. Howell et al., Phys. Rev. C21, 1153 (1980).
3. J. M. Moss, Invited Talk, International Symposium on Nuclear Reaction mechanisms; Fukuoka, Japan, Nov. 1978; W. D. Cornelius and J. M. Moss, to be published.
4. J. M. Moss, W. D. Cornelius and D. R. Brown, Phys. Rev. Lett. 41, 930 (1978); Phys. Lett. 71B, 87 (1977); Phys. Lett. 69B, 154 (1977).
5. S. Cohen and D. Kuruth, Nucl. Phys. A101, 1 (1967).
6. G. F. Bertsch et al., Nucl. Phys. A284, 399 (1977).
7. T. Hamada and I. P. Johnston, Nucl. Phys. 34, 382 (1962).
8. V. Gillet and N. Vinh Mau, Nucl. Phys. 54, 321 (1964).
9. H. V. Geramb et al., Phys. Rev. C12, 1697 (1970).
10. J. Delorme et al., Phys. Lett. 89B, 327 (1980).
11. H. Toki and W. Weise, Phys. Lett. 92B, 265 (1980).