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Anomalous Quenching of S=1 Two-Nucleon Transfer*

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ABSTRACT

Examination of the ground-state transitions of the (p,t) and (p,^{3}He) reactions on all T_z=1/2 nuclei from ^{21}Ne through ^{39}K reveals a systematic suppression of the S=1, T=0 component of the (p,^{3}He) transfer cross sections which is not explained in terms of current structure and reaction theories.

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In this letter we wish to call attention to a strikingly persistent feature of the ground-state transitions of (p,t) and (p,^{3}He) reactions on the T=1/2 nuclei of the sd-shell. These transitions populate mirror states with T=1/2 and T_z =±1/2, where both members of each isospin doublet should have essentially identical nuclear wave functions. The (p,t) reaction can populate these states only via pickup of a S=0,T=1 nucleon pair, while the (p,^{3}He) reaction can proceed via pickup of both S=0,T=1 and S=1,T=0, pairs. We have observed[1] that for every T=1/2 target in the sd-shell from ^{21}Ne through ^{39}K, the ground-state (p,^{3}He) transition appears to proceed without appreciable S=1,T=0 transfer.

At present we are unable to explain this anomaly. Significant S=1,T=0 strength is predicted by the best available shell-model wave functions for these ground-state transitions. Also, such strength is both predicted and observed for various excited states. On the basis of our observations, some aspect of either nuclear structure or direct-reaction mechanism serves to systematically quench the ground-state S=1,T=0 transfer strengths. The source of the quenching appears to lie outside the conventional realm of such theories. If this anomaly is confirmed by further experimental work, it will present a significant challenge to either current shell-model theory or DWBA theory, or both.

The experimental measurements employed 40 MeV protons from the Michigan State University cyclotron. The reaction products were momentum analyzed in a split-pole magnetic spectrograph and detected with position-sensitive proportional counters. This apparatus yielded excellent particle identification and energy resolutions in the range 15-30 keV. Angular distributions were usually measured in the region of 6° to 50°. In the context of the present note, the key experimental measurements were of the (p,^{3}He) to (p,t) cross section ratios. These measurements were typically made by measuring both (p,t) and (p,^{3}He) differential cross sections during the same experimental run, with the same configuration of target, beam, and counter. Only the magnetic field of the spectrograph was changed in order to bring both ^{3}He's and tritons to the same position on the focal plane. The errors in these relative cross section measurements are estimated to be less than 10%. Absolute cross section scales are estimated to be accurate to 20%. These were assigned by measuring elastic proton scattering counting rates relative to the (p,t) and (p,^{3}He) rates and assuming standard[2] optical model estimates for the elastic cross sections.

The ground-state angular distributions are shown in Fig. 1, with the (p,t) values elevated by one order of magnitude. The curves through the (p,t) distributions are DWBA calculations with a single set of optical model parameters, the proton values being adapted from Greenlees and Pyle[3] and the mass-3 values from Urone, et al.[4]. (The parameters used for the outgoing tritons and ^{3}He's are identical and have the characteristic that they fit ^{3}He and triton elastic scattering simultaneously.) The DWBA-curves have been generated with current[5-7] mixed configuration shell-model wave functions. However, the (p,t) shapes are independent of any variation of wave function within the sd-shell and the

absolute normalization of theory to experiment does not directly concern us in the present context. For the (p,^{3}He) reaction, the contributions to the complete calculated differential cross sections (solid curves) from S=0,T=1 transfer (dotted curves) and S=1,T=0, transfer (dotted-dashed curves) are shown separately. A "Gillet force"[8] was used for the spin-isospin exchange term in the interaction potential. The (p,^{3}He) DWBA calculations for these transitions have been multiplied by the same normalization factors which served to match the S=0,T=1 (p,t) DWBA calculations to the corresponding experimental (p,t) data. The shell-model S=0,T=1 contribution to (p,^{3}He) transfer is, of course, identical to that for the corresponding (p,t) transition. The shell-model wave functions, together with the theory-experiment normalization factors obtained from the (p,t) comparison, predict the additional amount of S=1,T=0 transfer strength for the (p,^{3}He) transitions shown by the dotted-dashed curves.

The uniform result for each of the nine pairs of mirror transitions shown in Fig. 1 is that the S=0,T=1 pickup strength, as predicted from the measured mirror (p,t) differential cross sections, reproduces all by itself the total observed (p,^{3}He) intensity. The addition of any significant amount of S=1,T=0 strength serves to make the predicted (p,^{3}He) differential cross sections too large, and often makes the agreement in shape worse too. This result is essentially independent of nuclear structure assumptions beyond the basic assumption that the mirror states have the same nuclear wave functions. It is anomalous in that no conventional theory, from the simplest one-component model through to full sd-shell space wave functions of many hundreds of terms, systematically predicts vanishing S=1,T=0 amplitudes for these transitions. In addition to typically predicting significant amounts of S=1,T=0 strength for ground-state transitions, such theories also predict signifiant, sometimes dominant, S=1,T=0 strength for various excited state transitions. Another aspect of the present anomaly, then, is that the S=1,T=0 quenching phenomenon appears to be confined to the ground states. Extensive evidence for S=1,T=0 transfer is seen[9] in the data on excited-state transitions.

Our results depend, of course, on the correct treatment of the reaction theory of relative (p,t) and (p,^{3}He) cross sections. We have tested our ability to correctly relate (p,t) and (p,^{3}He) cross sections via DWBA by analyzing differential cross sections to isobaric-analog (T=3/2) and to excited mirror (T=1/2) final states. We correctly predict the relative (p,^{3}He) to (p,t) cross sections for transitions to T=3/2 isobaric-analog states, which the selection rules allow to proceed only by S=0,T=1 transfer. On an opposite tack, we also correctly predict experimental cross sections for many of the transitions to excited mirror states in which the calculated (p,^{3}He) cross sections are dominated by the S=1,T=0 transfer component.

A quenching of the S=1,T=0 transfer component in ground state transitions was observed by Bass, et al.[10], who compared (^{3}He,n) and (^{3}He,p) reactions on ^{35}Cl, and by Hardy, et al.[11], who measured the (p,t) and (p,^{3}He) reactions on 0^+, T=1 target nuclei in the sd-shell. The generality of the phenomenon has not been recognized previously, however. Hardy, et al.[11], for example, attributed the S=1,T=0 quenching to the pick-up of paired nucleons from the same orbit. This explanation is not adequate to explain

our observations, however, since in the case of ^{33}S and ^{29}Si, for example, the pair of picked up nucleons come predominantly from two different orbits.

In a previous study of mirror (p,t) and (p,^{3}He) transitions on T_z=1/2 nuclei in the p-shell[12], several transitions with cross section ratios of (p,t) to (p,^{3}He) were found in which the (p,^{3}He) values were smaller even than the limits set by the corresponding (p,t) values. Interference terms arising through spin-orbit coupling in the optical potentials were suggested, though not tested, as a source of that anomaly. In none of our examples do the (p,^{3}He) cross sections fall below the S=0,T=1 limit set by the mirror (p,t) cross sections. This, together with significant S=1 strength observed for excited states, leads us to think that spin-orbit effects in the DWBA do not explain our present results. This is consistent with the conclusion of the quantitive analysis of Ref. 13, which finds that inclusion of spin-orbit coupling into the DWBA calculations alters cross sections by amounts which fluctuate from case to case within a range of about 10%.

The S=1,T=0 transfer component can directly be studied by means of the (d,α) and (α,d) reactions, since these must transfer only T=0 in the first order. Our present results suggest that the ground-state transitions of (d,α) reactions should be very weak. However, such data must be treated with some caution, since it has been suggested that the (d,α) reaction can proceed via isospin-violating second-order processes to a significant extent.[14] Further experimental work comparing (^{3}He,p) and (^{3}He,n) cross sections would also test the persistance of our effect.

If the solution to the present anomaly is sought in the area of nuclear structure, the goal can either be to find a mechanism particular to ground states which largely eliminates the S=1 two-nucleon overlap or to develop a theory with much enhanced S=0 overlap for ground states, so that in comparison the S=1 strength becomes negligible. The difficulties with these approaches are that the first requires a differentiation between ground and excited states more extreme than seems otherwise justified and that the second, if achieved, would disturb the relatively consistent reproduction of ground and various excited state strengths achieved for S=0 transfer with the present wave functions.

If the solution is sought in terms of reaction theory, a reasonable area to investigate would seem to be whether two-step processes, either sequential one-nucleon tranfer or inelastic scattering transfer coupling, can cause a selective interference such that the S=1 strengths to the ground states alone are quenched.

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FIGURE CAPTIONS

Fig. 1.--Angular distributions of mirror (p,t) and (p,^{3}He) ground state transitions on T_z=1/2 nuclei in the sd shell. The curves represent DWBA calculations. The same optical parameters are used for all nuclei. Proton parameters: V=45.5 MeV, r_o=1.20 fm, a=0.70 fm, W_D=14.0 MeV, r_o'=1.25 fm, a'=0.70 fm, r_c=1.25 fm. Mass-3 parameters: V=173.9 MeV, r_o=1.15 fm, a=0.72 fm, W=20.6 MeV, r_o'=1.50 fm, a'=0.82 fm, r_c=1.40 fm.