CHARGE EXCHANGE REACTIONS AND NUCLEAR MATRIX ELEMENTS

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Charge exchange reactions $(A_Z, A_{Z\pm1})$ induced by hadronic projectiles are a powerful tool for probing spin-isospin degrees of freedom in nuclei. The spin-isospin parts of the operators that mediate charge exchange reactions such as (p, n) are the same as those involved in the corresponding processes induced by electromagnetic and weak interactions. As a result, the matrix elements that describe hadronic charge exchange reactions are closely related to those that describe the rates of β decay or the cross sections of reactions induced by neutrinos. It would be fortunate if this relationship were quantitatively accurate, since it is often difficult to study the leptonic processes directly. For example, the range of excitation energy kinematically accessible in a β decay transition does not encompass the majority of the allowed (Gamow-Teller) strength and it is difficult to study neutrino induced reactions experimentally.

A promising direction of future activity is to determine leptonic strengths for otherwise inaccessible nuclides by studying charge exchange reactions using radioactive (secondary) beams in inverse kinematics [1]. This would provide nuclear properties important for problems of nuclear physics, particle physics, astrophysics and cosmology. One could clarify the relationship between the spatial properties of nuclear halo systems and nature of soft multipole modes. One could also determine the strength of neutrino-nucleus interactions needed to describe the chemical evolution of the Universe, especially the abundances of the light elements and the products of r-process nucleosynthesis, and to calibrate terrestrial detectors of supernova neutrinos.

However, it is not obvious a priori that the correlation of charge exchange and leptonic matrix elements is sufficiently close for this purpose. In contrast to leptonic processes, hadronic reactions involve operators that have an additional radial dependence and are subject to distortion by complex nuclear potentials; the medium renormalization of effective operators and the contributions of multi-step processes introduce additional uncertainties. Therefore it was an important advance to establish that there is an approximate proportionality between the cross section of charge exchange reactions at very forward angles leading to the Gamow-Teller (GT) excitations (with transferred $T = 1,\ L = 0,\ J = S = 1$) and the transition strength B(GT) determined by intrinsic nuclear matrix elements. The proportionality has been confirmed for strong transitions in a variety of nucleon and nucleus induced charge exchange reactions; a more detailed analysis is needed for weak GT processes. The model-independent character of the relation between the $L = 0$ cross section for reactions induced by ^{12}C projectiles and the GT strength was clarified by a theoretical analysis [2] based on a sensitivity function which identified the important part of the target transition density in momentum space.

In contrast to GT transitions, the first forbidden matrix elements of weak processes explicitly include orbital degrees of freedom. The corresponding nuclear response in the $L = 1$ channel is associated with the states forming the spin-dipole and giant-dipole charge-exchange resonances (SDR and GDR). There is very little information about the quantitative relationship of the charge exchange cross sections and leptonic strength for these excitations. Here we take a first step in providing this information by studying the relationship between first forbidden strength and (p, n) cross sections, both calculated from the same wave functions. We show that, on the same level of accuracy as in the GT case, for strong transitions one can expect an approximate proportionality between the observed cross sections of charge exchange reactions populating spin-dipole states and the corresponding nuclear transition probabilities. We follow the general approach that was successfully applied to GT excitations by Osterfeld *et al.* [2], extended to describe $L = 1$ transitions and the effects of the real part of the optical potential. Our results imply that there will be an approximate proportionality of the observed cross section at the maximum of the charge exchange reaction exciting spin-dipole modes and the leptonic strength. This supports the possibility of using such reactions for extracting leptonic strengths of astrophysical interest. Having established here the basic apparatus to examine this issue, it will next be important to examine transition densities for heavier nuclides, so as to determine whether their shapes are similar enough that cross sections and

B_J strengths will be proportional. It will also be important to examine the nature of the sensitivity functions for heavier nuclei, to ascertain whether they remain concentrated in a relatively small range of momnetum transfer where the transition densities are similar.

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