# Are spectroscopic factors from transfer reactions consistent with asymptotic normalization coefficients?

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It is extremely important to devise a reliable method to extract spectroscopic factors (SFs) from transfer cross sections. One would eventually like to have a very accurate probe that could test the predictions of the models and could disentangle the relevant elements of the NN force that are still missing, especially when moving toward the driplines. For exotic nuclei near or on the driplines, transfer reactions are a unique tool and, hence, can have a large impact in the programs of the new generation rare isotope laboratories. The standard framework for analysing transfer data with the intent of extracting SFs is the distorted-wave Born approximation (DWBA). Overall, it has been very successful in describing angular distributions at forward angles and less so for the larger angles where higher order become more important. The SF is the normalization needed for the calculated DWBA differential cross section to match the experimental one at forward angles. The uncertainty of the extracted SF resulting from the normalization of the DWBA cross section is assumed to be ~ 30%, even if the statistical errors are low. The reasons for this inaccuracy are typically attributed to ambiguities in the optical potentials, the inadequacy of the DWBA reaction theory, or the dependence on the single-particle potential parameters.

In Ref. [1], a combined method of extracting SFs from transfer reactions was introduced. This method can also be applied to breakup and *(e,e'p)* reactions. The combined method, which is based on the introduction of the asymptotic normalization coefficients (ANC) into the transfer analysis, allows one to significantly reduce the uncertainty in the choice of the bound state potential parameters and to test the DWBA or other underlying reaction theory. In the combined method the ANC should be determined from an independent measurement of a peripheral reaction while the SF is determined from transfer reactions which are sensitive to the nuclear interior. In [1] we emphasize that fixing the ANC is absolutely necessary, since even when the beam energy is well above the Coulomb barrier, most of the reaction happens in the asymptotic region.

In this work, [2], we expand on the ideas of the combined method, and explore other uncertainties (such as optical potentials and higher order effects) to attempt a unification of the SF and the ANC, searching for a reaction description which is practical and gives reliable spectroscopic information. We have studied transfer reactions to states considered good single particles, with three different Q-values, namely $^{14}C(d,p)^{15}C(g.s.)$ at the deuteron incident energy $E_d = 14$ MeV, $^{16}O(d,p)^{17}O(g.s.)$ at $E_d = 15$ MeV and $^{40}Ca(d,p)^{41}Ca(g.s.)$ at $E_d = 11$ MeV. All these reactions are above the Coulomb barrier and therefore contain some information from the interior. The standard DWBA method, using global optical potentials and the typical single particle parameters, produces SFs in agreement with shell model predictions, however the corresponding ANCs are not consistent with those extracted from independent measurements. If one imposes, within the DWBA formulation, ANCs that are consistent with the experimental values, the extracted SFs are significantly reduced compared to the shell model predictions. Some improvements on the SF/ANC mismatch can be obtained by using a deuteron optical potential fitted directly to the corresponding elastic data, at the relevant energy. In particular, for $^{16}O(d,p)^{17}O(g.s.)$ we obtain SF/ANC consistency. However the problem for the other two cases is not resolved. The deuteron adiabatic potential, which takes into account breakup, can change the SF up to 30%. This improves the situation for $^{14}C(d,p)^{15}C(g.s.)$ but fails to bring the $^{41}Ca$ ANC.

Contrary to *(e,e'p)* measurements, transfer reactions are surface peaked and it is disconcerting that the traditional methods to handle higher order effects at the surface are not able to solve the SF/ANC discrepancy for one of our test cases. The very fact that, even when the energies are well above the Coulomb barrier, there is such a large contribution from the peripheral region, makes it extremely important to pin down the ANC input unambiguously. We cannot rule out the possibility of a problem in the $^{41}Ca$ ANC we extracted from other data. Experiments to measure ANCs for this case are crucial to settle this matter. In the future we suggest that experiments be designed for the extraction of ANCs in parallel with the corresponding experiments aimed at extracting SFs. All three ANCs important for this analysis can be measured at the Cyclotron Institute, Texas A&M University. In particularly, the $^{15}C$ ANC is important for nuclear astrophysical reaction and will be measured in the near future.

[1] A. M. Mukhamedzhanov and F. M. Nunes, Phys. Rev. C **72**, 017602 (2005).
[2] D. Y. Pang, F. M. Nunes, and A. M. Mukhamedzhanov, Phys. Rev. C **75**, 024601 (2007).