Benchmark on neutron capture extracted from (d,p) reaction: application for ^{48}Ca(d,p)^{49}Ca and ^{48}Ca(n,γ)^{49}Ca

A. M. Mukhamedzhanov, P. Mohr,[1] and F. M. Nunes[2]
[1]*Strahlentherapie, Diakoniekrankenhaus Schwäbisch Hall, D-74253 Schwäbisch Hall, Germany,*
[2]*National Superconducting Cyclotron Laboratory and Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48864*

Reaction rates of capture reactions are a crucial input to astrophysical network calculations. In particular, neutron capture reactions, which play a pivotal role in the astrophysical r-process nucleosynthesis, have to be known for nuclei between the valley of *β*-stability and the neutron-drip line. Typically the neutron capture rates for the r-process have been estimated using the statistical Hauser-Feshbach model, although this may be unreliable away from stability as the level density is low. *(n,γ)* cross sections for short-lived unstable nuclei cannot be measured experimentally and have to be taken from theory. However, the production of unstable nuclei close to the r-process path has become possible in the recent years, and neutron transfer experiments like *(d,p)* on these nuclei are becoming more and more feasible as beam intensity continues to rise. It is important to underscore that such experiments can be done also at the Cyclotron Institute, Texas A&M University. It opens a possibility to use the *(d,p)* as indirect tool to determine the direct capture *(n,γ)*. Earlier we suggested [1,2] a combined method to determine the spectroscopic factors (SFs) from transfer reactions using the information about the asymptotic normalization coefficients (ANCs). Introduction of the ANC will allow us to determine the parameters of the bound state potential parameters and obtain more accurate SF. In this work we use this method to benchmark the *(d,p)* reactions to calculate the neutron radiative capture reactions. To test our method we applied it for analysis of the direct radiative capture reaction $^{48}Ca(n,\gamma)^{49}Ca$**.** We note that ^{48}Ca is considered to be a double magic nucleus, hence the ^{49}Ca ground state is well described as a single-particle neutron wave function bound to the core. To apply our method first we determine the ANC for $^{49}Ca \to {}^{48}Ca + n$ from the sub-Coulomb transfer reaction $^{48}Ca(d,p)^{49}Ca$ [3]**.** After that we determine the SF for the configuration $^{48}Ca + n$. Fortunately in the case under consideration direct measurements for $^{48}Ca(n,\gamma)^{49}Ca$ are available [4] and we can compare the SF and ANC determined from the radiative capture process with the ones obtained from the $^{48}Ca(d,p)^{49}Ca$ reaction**.** Results for the ground state of ^{49}Ca are shown in Fig. 1 for the SF $S(b)$ and ANC $C^2(b)$, respectively, where b is the single-particle ANC. As expected, the sub-Coulomb reaction is totally peripheral and provides the ANC $C^2 = 32.1 \pm 3.2\,\mathrm{fm}^{-1}$ for the ^{49}Ca (0.00 MeV) → ^{48}Ca (0.00 MeV) + *n*. $^{48}Ca(d,p)^{49}Ca$ reactions at 13 and 19 MeV deuteron energies are also peripheral and provide only the information about the ANC. However, the $^{48}Ca(d,p)^{49}Ca$ reactions at energies 30 and 56 MeV are not peripheral and, by comparing the $C^2(b)$ with the ANC C^2, one can determine (from their intersection) the single-particle ANC b and the SF $S = C^2 / b^2$. In Fig. 1 we also show $S(b)$ and $C^2(b)$ obtained for the direct radiative capture reaction $^{48}Ca(n,\gamma)^{49}Ca$**.**

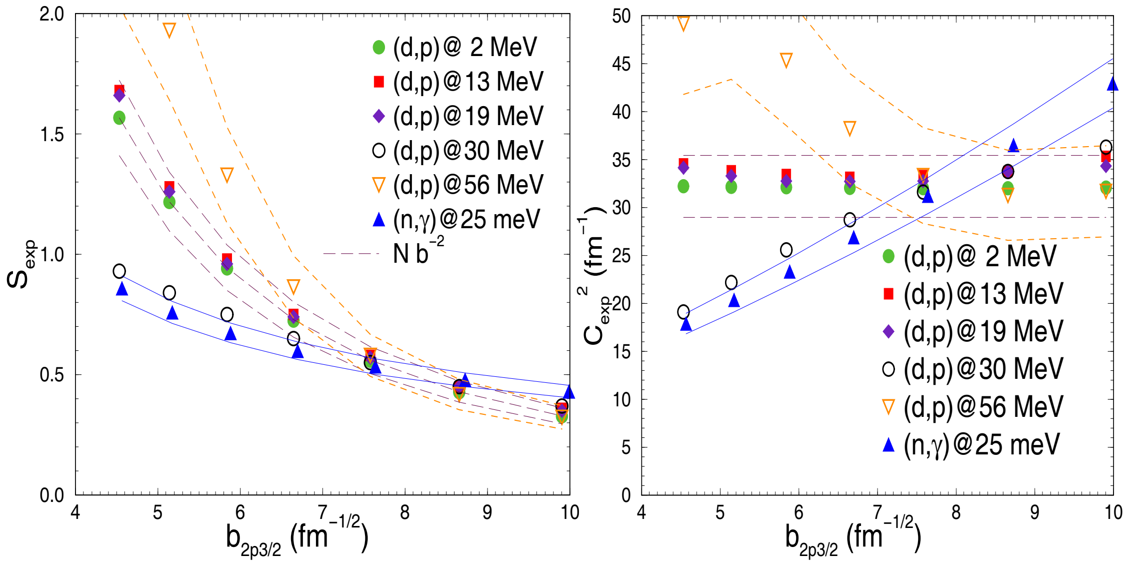

Figure 1. $S(b)$ and $C^2(b)$ from the $^{48}Ca(d,p)^{49}Ca$ reaction at E_d = 1.99 MeV (green dots), E_d = 13MeV (red squares), E_d = 19 MeV (purple diamonds), E_d = 30 MeV (open circles) E_d = 56 MeV (open triangles), and from $^{48}Ca(n,\gamma)^{49}Ca$ at 25 meV (blue triangles). Also shown are the experimental uncertainties in the *(d,p)* reaction at 1.99 MeV (dashed lines), at 56 MeV (long-dashed lines) and the *(n,γ)* reaction (solid lines).

As we can see the curves for *(n,γ)* and *(d,p)* reactions intersect with the sub-Coulomb curves at $b \approx 7.8$ fm$^{-1/2}$ confirming that the *(d,p)* and *(n,γ)* provide a consistent information about the SFs. Thus we can conclude that for ^{49}Ca both *(n,γ)* and *(d,p)* provide very close SF, i.e. *(d,p)* reactions can be used to determine the SF and calculate direct radiative *(n,γ)* reaction cross sections. The paper has been published in Phys. Rev. C **77**, 051601 (R) 2008.

[1] S. A. Goncharov *et al.*, Sov. J. Nucl. Phys. **35**, 383 (1982).
[2] A. M. Mukhamedzhanov and F. M. Nunes,, Phys. Rev. C **72**, 017602 (2005).
[3] J. Rapaport , A. Sperduto, and M. Salomaa, Nucl. Phys. **A197**, 337 (1972).
[4] H. Beer *et al.*, Phys. Rev. C **54**, 2014 (1996).