Transfer to the continuum calculations of quasifree (p,pn) and (p,2p) reactions

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Abstract

Nucleon removal (p, pn) and $(p, 2p)$ reactions at intermediate energies have gained renewed attention in recent years as a tool to extract information from exotic nuclei. The information obtained from these experiments is expected to be sensitive to deeper portions of the wave function of the removed nucleon than knockout reactions with heavier targets. In this contribution, we present calculations for $(p, 2p)$ and (p, pn) reactions performed within the so-called *transfer to the continuum* method (TR*). Results for stable and unstable nuclei are presented, and compared with experimental data, when available.

1 Introduction

Quasi-free nucleon removal reactions with proton projectiles, or (p, pN) reactions, have been extensively used to obtain information on the single-particle observables of nuclei. In these reactions, a proton beam of high-energy (> 100 MeV) collides with a nucleus with A nucleons, and events are selected in which one nucleon is extracted and a residual nucleus of $A - 1$ nucleons is detected, in either its ground or an excited state. In this regime of energies, the proton has a maximum mean free path in the nucleus so it can be assumed to interact only with the extracted nucleon, hence the name "quasi-free".

Thanks to the new facilities which produce beams with unstable nuclei, (p, pN) reactions have been extended to study unstable nuclei, employing re-

actions in inverse kinematics. These reactions are currently being measured and/or planned in facilities such as GSI or RIKEN, and their results are expected to be complementary to those of knockout reactions with heavier targets, since they are expected to be sensitive to more interior parts of the wavefunction of the extracted nucleon.

In this contribution we present calculations performed with the transfer to the continuum (TR*) formalism, which is more exhaustively described in [1] but whose main features will be indicated in the following section.

2 Theoretical formalism

The TR* formalism is very similar to the continuum-discretized coupled channels formalism (CDCC). In the former, we study the reaction $p + A \rightarrow p + N + C$ through the transition operator:

$$\mathcal{T}_{if} = \left\langle \Psi_{3b}^{(-)} | V_{pN} + U_{pC} - U_{pA} | \phi_{NC} \chi_{pA}^{(+)}(\vec{K}_{pA}, \vec{R}) \right\rangle , \tag{1}$$

in which the following approximations have been made:

1. The nucleus A is modelled as a system formed by the extracted nucleon N and a core C. As such, we use an optical potential U_{pC}, and the final wavefunction is approximated by a 3-body wavefunction $\Psi_{3b}^{(-)}$.

2. The incoming wavefunction between p and A is distorted by the potential U_{pA}. It must be noted that when $\Psi^{(-)}$ is the exact wavefunction of the effective 3-body problem, the matrix element is independent on U_{pA}.

The final 3-body wavefunction is expanded in states of a subsystem of two bodies with a defined energy and angular momentum. In the CDCC formalism, the subsystem chosen is $N - C$. In TR*, the selected one is the $p - N$ subsystem. Therefore, the calculations are very similar to those of transfer reactions, which gives the formalism its name.

At the energies considered, the CDCC formalism becomes impractical due to the large values of the $N-C$ angular momentum which must included in the calculations. On the contrary, TR* calculations have been shown to converge quite rapidly with the angular momentum of the $p - N$ subsystem [2] and they include naturally the (p, d) channel, which cannot be included in CDCC calculations.

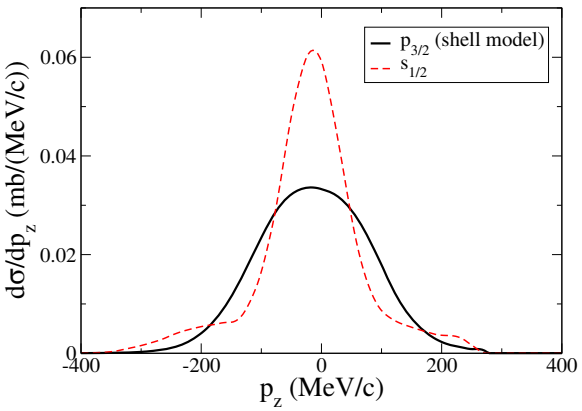


Figure 1: Longitudinal momentum distribution for ^{11}C$(p,pn)^{10}$C at 325 MeV/A, with spectroscopic factor equal to 1, assuming different ground state single-particle configurations for ^{11}C: $p_{3/2}$ (solid line), the single-particle state of the least bound nucleon of ^{11}C, according to mean field calculations and a fictitious $s_{1/2}$ state (dashed line).

3 Results

3.1 ^{11}C$(p,pn)^{10}$C at 325 MeV/A

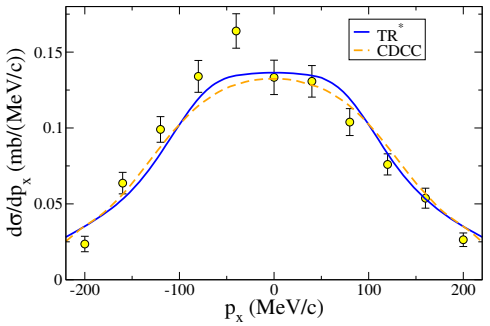
First, we present calculations for the (p,pn) reaction on nuclei of ^{11}C performed at 325 MeV/A. For the V_{pn} potential we have used the Reid93 interaction [3] while the U_{pC}, U_{nC} and U_{pA} interactions have been calculated through a folding of the Paris-Hamburg g-matrix effective NN interaction [4] with the nuclear density of the nucleus, obtained from a Hartree-Fock calculation with the Skyrme NN interaction.

In Fig. 1 we present the longitudinal momentum distribution assuming different single-particle configurations for the ground state of ^{11}C. The solid line corresponds to a neutron extracted from a $p_{3/2}$ orbital, the least-bound neutron according to mean field calculations. We also present calculations in which the nucleon is extracted from a $s_{1/2}$ orbital, with the same separation energy. As can be seen in Fig. 2, the momentum distribution is very sensitive to the angular momentum of the extracted nucleon.

3.2 ^{18}C$(p,pn)^{17}$C* at 81 MeV/A

We have performed calculations for the reaction ^{18}C$(p,pn)^{17}$C* leading to the ^{17}C in its excited $5/2^+$ state. This reaction was measured by Kondo *et al.* [5], and was compared to a CDCC calculation [5]. We present a TR* calculation: the Reid93 interaction was used for V_{pn} while for $U_{p^{18}C}$, $U_{p^{17}C}$ and $U_{n^{17}C}$ a folding of the JLM interaction [6] with the ground state densities of the corresponding nuclei was employed.

Calculations are rescaled in order to reproduce the experimental data, and the required factor is compared with the theoretical spectroscopic factor



	TR*	CDCC	Theor.
S_F	2.11	2.13	2.80

Figure 2: Transversal momentum distribution for $^{18}\mathrm{C}(p,pn)^{17}\mathrm{C}^*$ at 81 MeV/A. TR* and CDCC calculations are presented. (CDCC and experimental data are extracted from [5]). Spectroscopic factors (S_F) are presented for both calculations.

(S_F), obtained with a shell-model calculation with the WBP interaction [7]. We find a very good agreement between both calculations and the experimental data, which validates the use of TR* in this regime of energies.

4 Conclusions

Preliminary calculations indicate that the TR* provides a suitable framework to study (p,pN) reactions at energies of ~ 100 MeV/A. We expect the method to be adequate at higher energies, of around hundreds of MeV/A, where the CDCC method becomes unfeasible.

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