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Short-range (pairing) versus long-range (collective) correlations in two-neutron transfer reactions induced by ^{18}O

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Short-range (pairing) versus long-range (collective) correlations in two-neutron transfer reactions induced by ^{18}O

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Abstract. It is shown that the pairing correlation is very important for the elastic two-neutron transfer reactions, for reaction induced by 84 MeV ^{18}O on several targets with low collectivity in its ground state (spherical), proceeding through the one-step process. For the transition to lower excited states, the one-step process also dominated, for the final nuclei having low collectivity. On the contrary, if the collectivity of these states is considerable, the two-neutron transfer reaction is dominated by a two-step process through an intermediate partition.

1. Introduction

Transfer reactions have been used during several decades to obtain spectroscopic information of the colliding nuclei [1-4]. The single nucleon transfer reactions are used to study the single particle components of the wave functions of the initial and final states. The two-particle transfer reactions are mainly devoted to the search of signatures of pairing correlations between the two transferred nucleons. Alpha particle transfer reactions are intended to determine the cluster components of the wave functions. Finally, multinucleon transfer reactions are used to study nucleon correlations in this complex phenomenon and to produce nuclei far from the stability line because of their unique structural properties. Sometimes transfer reactions are also used to produce radioactive beams [5].

In this kind of transfer reactions, there are four important ingredients to succeed in the full description of the reaction mechanism. They are the nuclear reaction theoretical model, the optical potentials for different partitions, the spectroscopic amplitudes and the transition form-factors. The use of prior or post representations of the Hamiltonian usually helps to derive some observables, and the nonorthogonality between different partitions has to be accounted for.

Nevertheless, in some cases, the transfer reactions are the “undesired channels”. This is the case of the NUMEN project [6-8] that is focused on the determinations of the double charge exchange nuclear matrix element in connection to those of neutrinoless double beta decay. Having a reaction in which the mass is conserved but the two interacting nuclei exchange two charge units trough charged meson exchange (in one- or two-step, something that still has to be determined), one has to worry about the fact that in the observed cross section may be contributions of the two-step (two correlated neutrons and two correlated protons), three-step (two correlated protons (neutrons) and two uncorrelated neutrons (protons), and four step (two uncorrelated protons and two uncorrelated neutrons in any order) transfer reaction starting and ending with the same initial and final partition [9]. In this case, the undesired contribution of transfer channel has to be determined with a high precision in order to access to the desired double charge exchange nuclear matrix element.

Having this in mind, our group has been devoted in the last couple of years to improve the reaction theory in order to access to the calculation of the transfer reaction having in mind the four factors mentioned above (proper microscopic reaction model, microscopic spectroscopic amplitudes, form factors and optical potentials) to derive reliable transfer cross sections, and to have the ability to determine transfer cross sections with confidence at least its order of magnitude. To accomplish our goal we have compared our theoretical results with high-quality data measured using the large acceptance MAGNEX spectrometer at the INFN-Laboratori Nazionali del Sud, in Catania, Italy [10,11].

In the present work we summarize some of our results concerning the two-neutron transfer reactions $^{12}C(^{18}O,^{16}O)^{14}C$ [12,13], $^{13}C(^{18}O,^{16}O)^{15}C$ [13-16], $^{16}O(^{18}O,^{16}O)^{18}O$ [17,18] and $^{64}Ni(^{18}O,^{16}O)^{66}Ni$ [19]. We will emphasize the similarities of the two-neutron elastic transfer of all these system, concerning the effect of pairing correlations between the two transferred neutrons, and the difference of the transfer to the first 2+ excited states of ^{66}Ni, for which long-range correlations prevail, to the transfer to the low-lying states of the other systems, for which the short-range pairing correlations remain important.

This work is organized as follows. The next section is devoted to the results and discussions while in the last section we give some remarks and show some perspectives on our work.

2. Results

To access to the effect of the pair correlations in the two-neutron transfer reactions we have performed two kinds of reaction calculations. The first group corresponds to the one-step (paired) two-neutron transfer models. Here the extreme cluster model and independent coordinates models were used (for details see refs. [12,14, 17-19] and references therein). The first model considers that the two neutrons are coupled antiparallel to total spin zero in the 1s state and separated to the core with different angular momenta. In the independent coordinates, the quantum numbers and coordinates of both particles are followed, and all possible combinations of the sum of the spins and angular momentum are considered according to the angular momentum and parity conservation rules. All the calculations were performed using the fresco code [20]. In the case of one-step calculations coupled reaction channels calculations (CRC) were performed. In the case of two-step transfer, coupled channel Born approximation (CCBA) calculations were performed, including couplings to all orders in the entrance partition and first-order distorted wave approximation (DWBA) between partitions.

The São Paulo potential [21] was used for both real and imaginary part of the optical potential in all partitions. In the entrance partitions, a strength factor of 0.6 was used for the imaginary part [22]. This factor accounts for the missing couplings to dissipative processes, as well as, for the coupling to continuum states, which are not explicitly considered in the calculations. In the outgoing and intermediate partitions, the strength factor for the imaginary part of the optical potential was set equal to 0.78 because no couplings were included. This coefficient was proved to be suitable for describing the elastic scattering cross section for many systems in a wide mass and energy intervals [23-25].

The spectroscopic amplitudes were determined performing extensive shell-model calculations with the NUSHELLX code [26]. Table of the spectroscopic amplitudes for the projectile and target overlaps, and the details of the interaction and model spaces used are given in refs. [12, 14, 17-19]. As mentioned above, all the experimental data were measured at Laboratori Nazionali del Sud. The details can be found in refs. [12,14, 17-19].

In Figure 1 (a) and (b) the results for the one-step, using the microscopic independent coordinates model (full line), and for the two-step (dashed lines) transfer reactions, compared to the experimental data for the ground state (g.s.) (a) and for the 2^+ (8.33 MeV) of the ^{14}C (b) in the $^{12}C(^{18}O,^{16}O)^{14}C$ [12] reaction. One can see that for the transfer to both the ground and the excited state of ^{14}C the pairing correlations prevail (especially for the excited state). The same result was found for the low-lying excited states of ^{15}C in the $^{13}C(^{18}O,^{16}O)^{15}C$ [14] reaction, showing that the extra neutron (even nucleus) was not able to considerably disturb the correlation the two neutrons in the two-neutron transfer. Also, the same result was obtained in the transfer of two neutrons to low-lying states [17] and the high natural parity excited states of ^{18}O [18] in the reaction $^{16}O(^{18}O,^{16}O)^{18}O$.

Recently [19], we also studied the two-neutron transfer reaction for the $^{64}Ni(^{18}O,^{16}O)^{66}Ni$ system. The results using the shell model for the calculations of the spectroscopic amplitudes are shown in Figure 1 for the g.s. (a) and the first excited state (b) of ^{66}Ni. One can see that in this case, the elastic transfer follow the same results as for all the other more light systems mentioned above. On the contrary, the transfer to the first excited state of ^{66}Ni is dominated by the two-step process. The reason for that may lay in the fact that this state of Nickel has stronger collectivity that the excited states of the other systems studied before. To prove this we show in Table 1 the results of the reduced quadrupole transition probabilities for systems (including the ones that we are studying here).

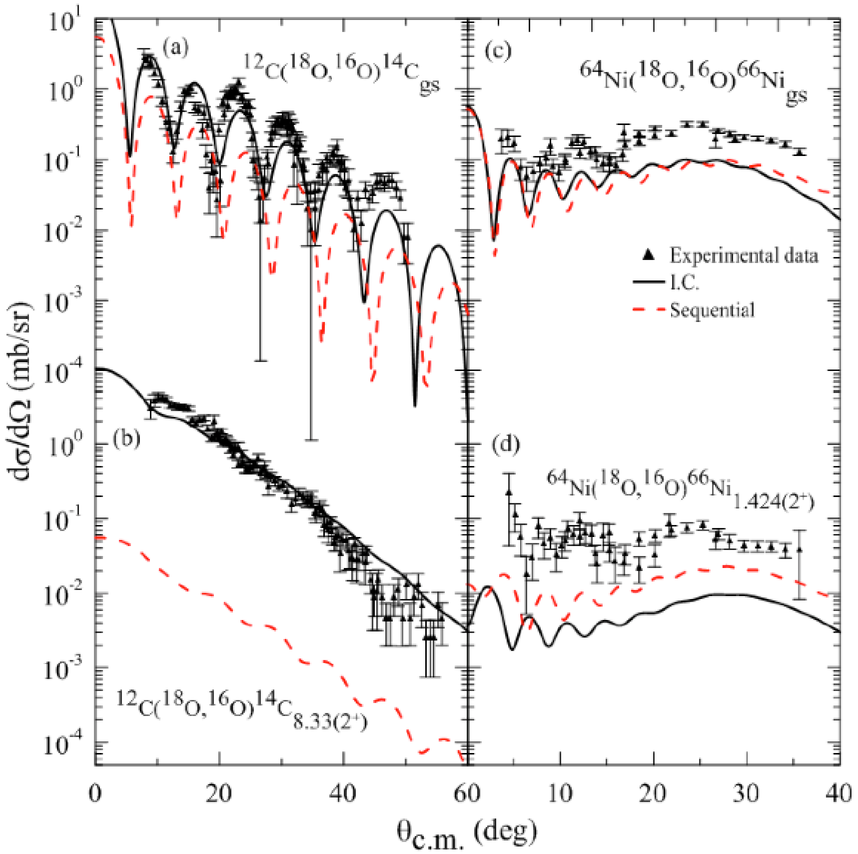

Figure1: Comparison of one-step (IC) and two-step (sequential) two-neutron transfer angular distributions with the experimental data for the ^{12}C(^{18}O,^{16}O)^{14}C [12] and ^{64}Ni(^{18}O,^{16}O)^{66}Ni [19] reactions.

Table 1. Electric quadrupole reduced transition probabilities [27].

Nucleus	**B(E2); 0$^+$→ 2$^+$ (e^{2}b^4)**
^{14}C	0.0018
^{18}O	0.0045
^{66}Ni	0.060
^{76}Ge	0.270

From Table 1 it is clearly seen that, the collectivity of the ^{66}Ni and ^{76}Ge nuclei are in fact bigger. In fact, in ref. [28] Lemaire and Low obtained similar results, as we obtained here for ^{66}Ni, for the two-neutron transfer to the g.s. and the first excited state of the ^{76}Ge nucleus.

3. Conclusions

In the present work, we have shown that the pairing correlation is very important in two-neutron transfer reactions for the final states having low collectivity, leading to the very important one-step process. Nevertheless, when the collectivity of the final states is important, the role of pairing correlations is not so relevant, and the two-step transfer reaction prevails. It would be very important to study if the pairing correlation is also important in the two-proton and deuteron transfer reactions.

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