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Two-neutron clustering aspects in the transitions induced by the $^{13}C(^{18}O,^{16}O)^{15}C$ reaction at 84 MeV incident energy

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Abstract. The $^{13}C(^{18}O,^{16}O)^{15}C$ reaction is studied at 84 MeV incident energy. The measured cross-section angular distributions are analysed by exact finite-range coupled reaction channel calculations. The two-particle wave functions are extracted using the extreme cluster and the independent coordinate scheme with shell-model derived coupling strengths.

1. Introduction

Direct two-nucleon transfer reactions play an important role in understanding specific properties of the atomic nuclei as for example pairing correlations [1] [2]. Among these, heavy-ion direct transfer reactions at energies close to the Coulomb barrier are useful tools to obtain precise spectroscopic information. Over the last few years, a systematic study on heavy-ion induced one- and two-neutron transfer reactions on different target nuclei was pursued at the INFN-LNS (Italy) by the $(^{18}O,^{17}O)$ and $(^{18}O,^{16}O)$ reactions. Many nuclear systems were explored using the MAGNEX spectrometer [3] to detect the ejectiles. Thanks to its high resolution and large acceptance, high quality inclusive spectra were obtained, even in a largely unexplored region above the two-neutron separation energy in the residual nucleus [4] [5] [6]. New phenomena were unveiled, such as the dominance of the direct one-step transfer of the two neutrons [7] and the presence of broad resonances at high excitation energy in the ^{14}C and ^{15}C spectra. The latter were recently associated to the first experimental signature of the Giant Pairing Vibration [8] [9]. A thorough analysis of the broad structures populated in the $^{13}C(^{18}O,^{16}O)^{15}C$ reaction at high excitation energy, above the two-neutron emission threshold, was presented in ref. [10] and the neutron decay of these structures was investigated in ref. [11]. Moreover, it was demonstrated that the $(^{18}O,^{16}O)$ two-neutron transfer reaction can be used for quantitative spectroscopic studies of pair configurations in nuclear states [12] [13].
From a theoretical point of view, the Coupled Reaction Channel (CRC) approach is necessary to interpret such data. In ref. [12] the experimental absolute cross section of the one- and two- neutron transfer reactions induced by an ^{18}O beam on a ^{12}C target was reproduced for the first time without the need of any scaling factor by means of Exact Finite Range (EFR) CRC calculations. In this manuscript, we analyse the absolute cross section angular distributions for some transitions populated by the $^{13}C(^{18}O,^{16}O)^{15}C$ two-neutron transfer reaction at 84 MeV incident energy in the same framework of our previous work [12].

2. The experiment and results

The experiment was performed at the INFN-LNS laboratory in Catania with an $^{18}O^{6+}$ beam at 84 MeV incident energy that impinged on a thin ^{13}C target. Runs with ^{12}C target were also recorded for estimating the background coming from the ^{12}C impurities in the ^{13}C target. The ejectiles were momentum analysed by the MAGNEX spectrometer working in the full acceptance mode [3]. The particle identification and the data reduction technique are the same described in details in refs. [9] [14]. The horizontal and vertical position and angles of the ^{16}O ejectiles, measured by the Focal Plane Detector (FPD) [15] [16], were used as input for a 10^{th} order ray-reconstruction, based on the differential algebraic method implemented in MAGNEX [17] [18].

An example of the obtained energy spectra for the ^{15}C nucleus is shown in Fig. 1 (left panel), in which the ^{14}C background spectrum coming from the ^{12}C impurities in the ^{13}C target is superimposed, after normalization. Several bound and resonant states of the ^{15}C nucleus are recognized, which are almost the same strongly populated in the (t,p) reactions on ^{13}C [19]. In particular, below the one-neutron separation energy (S_n = 1.218 MeV) the only two ^{15}C bound states are identified, i.e. the ground (J^{π} = $1/2^+$) and the $5/2^+$ state at E_x = 0.74 MeV, that are characterized by a dominant single particle configuration [20]. In the region between S_n and the two-neutron separation energy (S_{2n} = 9.39 MeV), narrow resonances at E_x = 3.103 ($1/2^-$), 4.22 ($5/2^-$), 4.66 ($3/2^-$), 6.84 ($9/2^-$, $7/2^-$), 7.35 ($9/2^-$, $7/2^-$) MeV are populated. All of these states are indicated to consist mainly of $2p$-$1h$ configurations (with respect to the $^{14}C_{g.s.}$ vacuum state) [19]. Resonances with a single-particle configuration of a $^{14}C_{g.s.}$ + $1n$ [21] are very weakly populated in the present reaction.

The obtained absolute cross section angular distributions for the ground state and the resonance at 4.22 MeV are shown in Fig. 1 (right panel).

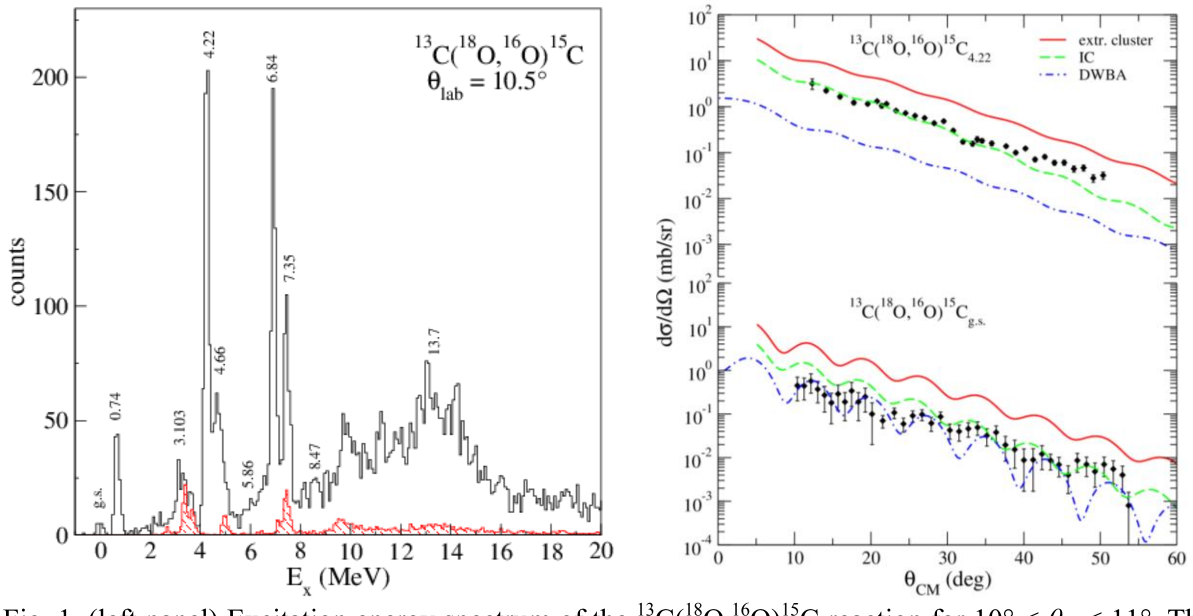

Fig. 1. (left panel) Excitation energy spectrum of the $^{13}C(^{18}O,^{16}O)^{15}C$ reaction for 10° < θ_{lab}< 11°. The red-hatched area corresponds to the background that comes from ^{12}C impurities in the target. (right panel) Experimental cross section angular distributions for the transitions to the g.s. and the state at 4.22 MeV in ^{15}C. Theoretical calculations: extreme cluster calculations (red line), independent coordinate calculations (green line) and two-step sequential DWBA calculations (blue line).

3. Theoretical calculations

Exact finite range coupled reaction channel (CRC) and two-step distorted wave Born approximation (DWBA) calculations for two-neutron transfer reactions were performed to describe the cross section, using the FRESCO code [22], using the same ingredients of ref. [12] [23]. Two different models were adopted for the two-neutron transfer: the first is a direct, simultaneous transfer

of the two particles, and the second is a two-step sequential mechanism, which goes through the ^{17}O + ^{14}C intermediate partition. The two-particle wave functions for the one-step two-neutron transfer mechanism were obtained considering two different schemes: i) the extreme cluster model approximation, in which the relative motion between the two transferred neutrons is frozen and separated from the core and the two neutrons are coupled antiparallel to an intrinsic angular momentum S = 0, with spectroscopic amplitudes for both target and projectile set to 1.0; ii) the Independent Coordinate (IC) model, in which two-neutron spectroscopic amplitudes determined performing shell-model calculations were used. These calculations assume the ^{12}C as closed core and valence protons and neutrons in the $1p_{1/2}$, $1d_{5/2}$, $2s_{1/2}$ orbits. The effective phenomenological *zbm* interaction [24] was used. Two-step DWBA calculations for the sequential mechanism of two-neutron transfer were also performed in order to check the importance of the two-step mechanism.
The resulting differential cross sections for the direct and the sequential transfer for the ground and the state at 4.22 MeV are shown in Fig. 1 (right panel). The extreme cluster model calculation gives a larger cross section than the data, whereas the IC calculations describe them quite well. The two-step sequential DWBA calculations are much lower than the data for the transition to the 4.22 MeV state, but they are of the same order of the data in the case of the ground state. This difference confirms that the ground state has a dominant single-particle configuration and indeed it is weekly populated in the spectrum (see Fig. 1), whereas the 4.22 MeV state as a dominant $^{13}C_{g.s.}$ + 2n configuration and it is strongly populated in a direct two-neutron transfer mechanism.

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