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2011 J. Phys.: Conf. Ser. 312 082016

(http://iopscience.iop.org/1742-6596/312/8/082016)

Enhancement of the two neutron transfer channel in ^{18}O induced reactions at 84 MeV

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Abstract. A study of the yields for different reaction channels has been performed at the Catania INFN-LNS laboratory using a ^{18}O beam on ^{13}C and ^{12}C targets. The ejectiles have been momentum analyzed by the MAGNEX magnetic spectrometer. The achieved mass resolution (about 1/160) has allowed to identify the reaction products corresponding to different reaction channels. The measured yields show an enhancement of two neutrons transfer channel compared to one. This result demonstrates that the (^{18}O, ^{16}O) reaction proceeds mainly by the direct transfer of the neutron pair, with small contributions from second order processes.

1. Introduction

Two nucleon transfer reactions can test the pairing interaction, which gives extra binding energy to pairs of nucleons coupled to angular momentum zero [1-2] and represents one of the main contributions to the residual interaction, when a mean field picture of nuclei is used [3].

Because of the pairing interaction these processes can proceed not only through the sequential transfer of two single nucleons, but also through the direct transfer of one correlated pair [4].

In the extreme case of infinitely strong pairing correlation this one-step mechanism is expected to prevail, instead the two-step sequential process should be dominant in the case of pure uncorrelated nucleons. Therefore the interplay of these two processes is crucial to understand the role of pairing correlations in nuclei and consequently to build a microscopic description of nuclei beyond the mean field approximation.

In addition the detailed description of these transfer reactions could provide useful information to the reaction mechanism point of view. In fact the expected competition between one and two-step mechanisms in the two neutron transfer could help to approach the problem of the interference in a more quantitative way [5].

If the reaction mechanism is dominated by the direct transfer of the neutron pair it is expected a strong enhancement of the $L = 0$ channel.

This is an important factor, for example, for the observations of the *Giant Pairing Vibration* mode (*GPV*), predicted for heavy nuclei at high excitation energy (~ 70 $A^{-1/3}$) by Broglia and Bes [6]. These giant modes should be populated in two nucleon transfer reactions, but have never been experimentally observed.

In this context the incident energy range takes an important role. Reactions near the Coulomb barrier minimize the angular momentum transfer, but in this conditions the angular distributions are peaked at the grazing angle and are not very sensitive to the structure of the populated states. Moreover Q-value matching rules typically suppress the cross section at high excitation energy.

Otherwise at high incident energy (E_{inc} > 10 MeV/u) the reactions are characterized by large amount of angular momentum transfer and the contribution form deep inelastic process becomes relevant.

However for energies between 5 and 10 times the Coulomb barrier the angular distribution are sensitive to the details of the final populated states [7].

In this energy range the (^{18}O,^{16}O) reaction seems to be a good candidate for the $L = 0$ transitions.

In fact, from the Brink's matching conditions [8] one obtains that the probability to transfer $L = 0$ angular momentum is not negligible.

Furthermore in the ^{18}O nucleus there is a preformed neutron pair in the sd-shell that could survive in the target nucleus if the same orbital is available (as, for example, in the ^{13}C, ^{14}C, ^{16}O nuclei).

2. Experimental settings

The experiment has been performed at LNS-INFN in Catania, using a Tandem beam of ^{18}O on a 50 μg/cm^2 self supporting ^{13}C and ^{12}C target at 84 MeV incident energy.

The outgoing ejectiles were momentum analyzed by the MAGNEX spectrometer and detected by the focal plane detector FPD [9-10]. The FPD was filled with 99.95% pure isobutane gas at 7 mbar pressure. In the data presented in this paper the spectrometer was located at a central angle of 6° with respect to the beam incidence direction. Due to the large angular acceptance of MAGNEX (horizontally –0.090 rad, +0.110 rad, vertically ±0.125 rad in the spectrometer reference frame), this setting covers an angular range of about $4° < \theta_{lab} < 13°$ in the laboratory reference frame.

The magnetic field was set in order to focus the ^{16}O ejectiles relative to the $^{15}C_{g.s.}$ and $^{14}C_{g.s.}$ respectively in the focal plane position corresponding to a momentum deviation $\delta = 0.08$ with respect to the central trajectory.

3. Data analysis

In order to measure the yields of the different reaction channels, it is necessary to well identify the transmitted ejectiles at the focal plane both in charge and mass.

The FPD is a gas-filled hybrid detector with a wall of 54 Silicon detectors at the back. The detector measures the horizontal and vertical coordinates and angles of each incident particle and also the energy loss in the gas and the residual energy released in the silicon detectors wall [9].

The Z identification was obtained using the standard ΔE-E technique. As for mass identification it was used an innovative technique based on the relation describing the trajectory of a particle in a magnetic spectrometer: $B\rho = \frac{p}{q}$. With this identification technique a mass resolution as high as 1/160 has been reached [11].

In Fig.1(a) the resulting yields for the inelastic, one neutron and two neutron stripping channels are shown for the reaction ^{18}O + ^{13}C. These have been calculated taking into account the efficiency in the production of the different charge states using the program INTENSITY [12] (the 8^+, 7^+ and 6^+ charge states are considered).

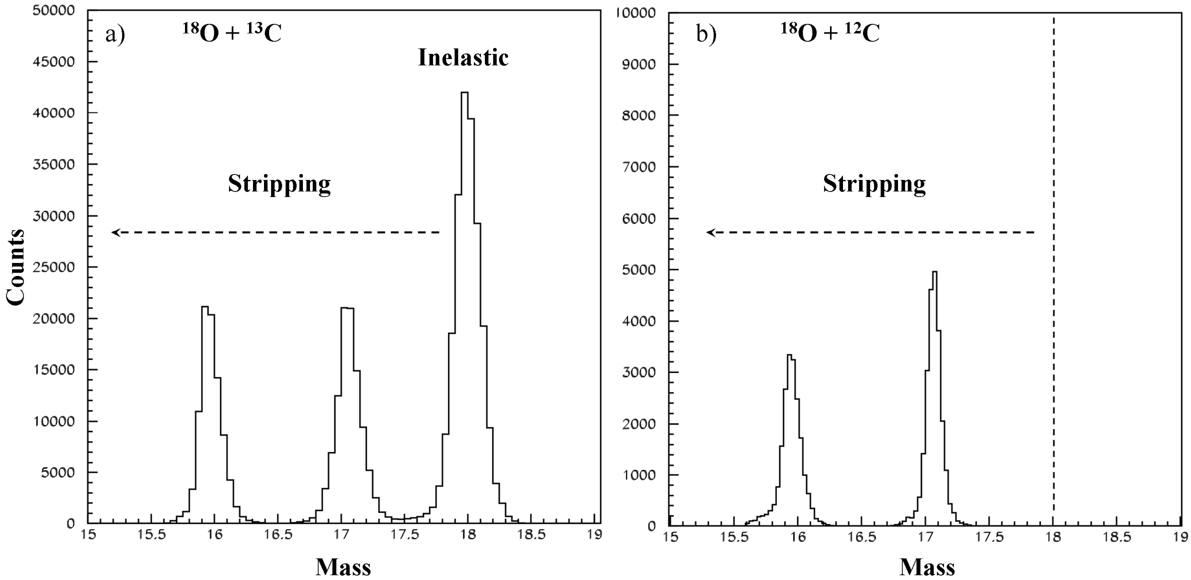

Figure 1 Yields of different oxygen ions (^{18}O, ^{17}O, ^{16}O) calculated taking into account the efficiency function for the different charge states (8^+, 7^+ ,6^+) using the program INTENSITY [12] for the reactions $^{18}O + ^{13}C$ (a) and $^{18}O + ^{12}C$ (b)

The striking result is that the two neutron transfer process appear as probable as the one neutron transfer, both of them are about an order of magnitude less than the inelastic process.

The same behaviour appears considering the ^{12}C target (Fig.1(b)) , where the inelastic peak is not displayed because it was probably contaminated with a beam halo.

4. Discussion

The unexpected enhancement of ^{16}O isotopes observed in Fig.1 suggests that the two neutron transfer process has a relevant contribution from the direct transfer of the neutron pair, instead of being only a second order process. In fact, if there was only the contribution from the sequential transfer of the two neutrons it would be expected a transition amplitude given by the product of two independent terms and consequently the experimental yields should be much lower than the measured ones.

If there is such a contribution from the direct transfer of the neutron pair a strong enhancement of the $L = 0$ channel is expected.

In Fig.2 two preliminary reconstructed spectra of ^{15}C in two different angular settings are shown. Several bound and resonant states are observed and identified in the low excitation energy region. All the labelled ^{15}C states have been observed by (t,p) reactions [13]. In Table 1 the angular momenta transferred in these transitions are listed. There is only one $L = 0$ transition known, which is that to the 3.1 MeV state of ^{15}C. However the strength observed for this state is not enough to account for the enhancement of the direct process deducted from the yield of ^{16}O isotopes.

Therefore one expect that the $L = 0$ strength transition could be present in another part of the spectra.

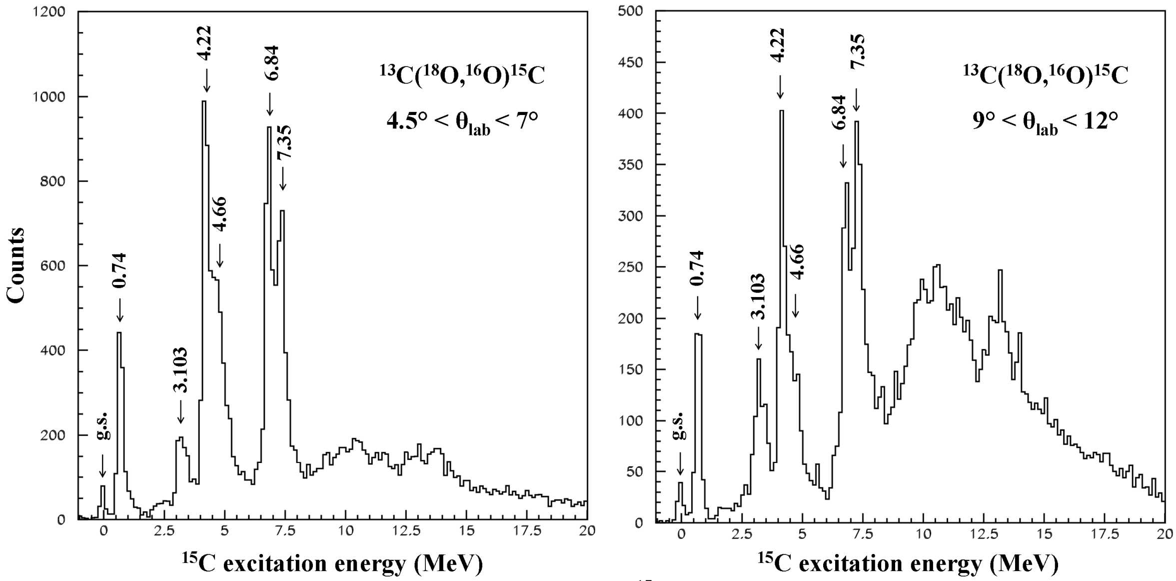

Figure 2 Spectra of the reconstructed excitation energy of ^{15}C in two angular settings 4.5° < θ_{lab} < 7° (a) and 9° < θ_{lab} < 12° (b). The isolated peaks are labelled with the relative excitation energy in MeV.

In the energy spectra shown in Fig.2 a broad structure located between 10 and 15 MeV is evident. Its behaviour in these two angular ranges seems similar to the 3.1 MeV state. This could suggest that the transition which populate this structure is also an L = 0.

If it was so this structure could represent the first experimental evidence of the GPV resonance. This result confirms previous findings (see Ref.[14-15]).

Table 1 Angular momentum transferred in the transitions from $^{13}C_{g.s.}$ to different excited states of ^{15}C [13].

Transition	Angular momentum transferred
$^{13}C_{g.s.}(1/2^-) \rightarrow {}^{15}C_{g.s.}(1/2^+)$	$L = 1$
$^{13}C_{g.s.}(1/2^-) \rightarrow {}^{15}C_{0.74}(5/2^+)$	$L = 3$
$^{13}C_{g.s.}(1/2^-) \rightarrow {}^{15}C_{3.103}(1/2^-)$	$L = 0$
$^{13}C_{g.s.}(1/2^-) \rightarrow {}^{15}C_{4.22}(5/2^-)$	$L = 2$
$^{13}C_{g.s.}(1/2^-) \rightarrow {}^{15}C_{4.66}(3/2^-)$	$L = 2$
$^{13}C_{g.s.}(1/2^-) \rightarrow {}^{15}C_{6.84}(7/2^-,9/2^-)$	$L = 4$
$^{13}C_{g.s.}(1/2^-) \rightarrow {}^{15}C_{7.35}(7/2^-,9/2^-)$	$L = 4$

5. Conclusions

We observed an enhancement of the two neutron transfer process compared to one. This suggests an important contribution from the direct transfer of the neutron pair.

The analysis is still in progress for data measured at other angular settings (12°, 18°, 24°) and other targets (^{9}Be, ^{11}B, ^{28}Si, ^{58}Ni, ^{64}Ni, ^{120}Sn, ^{208}Pb) [16].

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