Selectivity of the (^{18}O,^{16}O) two-neutron transfer reaction

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Abstract

A study about the selectivity of the ^{12}C(^{18}O,^{16}O)^{14}C two-neutron transfer reaction was done at the Catania INFN-LNS laboratory at 84 MeV incident energy, that corresponds to about three times the Coulomb barrier. The ejectiles produced in the reactions were momentum analyzed and identified by the MAGNEX spectrometer. The achieved mass resolution in the particle identification (about 1/160) has allowed to identify the different reaction products (mainly isotopes of C, N, O, F, Ne). The integrated cross sections show an enhanced yield for the two-neutron transfer compared to the one-neutron transfer.

The *Q*-value spectrum was extracted and several known bound and resonant states were identified. In particular states with 2p-4h configuration respect to the ^{16}O core are mainly populated by the (^{18}O,^{16}O). This result is a first evidence that the (^{18}O,^{16}O) reaction proceeds mainly by the direct transfer of the neutron pair, instead of a second order process.

1 Introduction

Two-neutron transfer reactions are useful probes to study details of the neutron-neutron correlations beyond the nuclear mean field, in particular they play an important role to test the pairing interaction between the nucleons. The concept of pairing force was introduced in the thirties to explain the major stability of even-even nuclei respect odd systems [1]. In the two-neutron transfer reactions this force favors the direct transfer of a pair coupled to $L = 0$ angular momentum, in addition to the standard uncorrelated sequential transfer of two single nucleons [2-3]. In certain dynamic conditions the direct transfer can be dominant and pairing modes are more efficiently excited in a residual nucleus [4].

In the past, such spectroscopic studies were carried out mainly using (t,p) reactions [5]. During the course heavy ion beams were also available. Despite the apparently more complicated structure of heavy projectile, there are many reasons that lead to prefer the reactions between heavy ions rather than those induced by light ions. First and foremost the reaction mechanism is a much simpler for heavier projectiles. In fact, all quasi-elastic heavy-ion-induced processes can be treated in a semi-classical approximation. This simplicity often leads to a more clearly defined spectroscopy about the target and, in case of heavy ions, the projectile [6-7]. In fact there is the possibility of exciting the projectile as well as the target. Transfer reactions between heavy ions at energies above the Coulomb barrier have a large cross-section if certain kinematical conditions (known as Brink matching), on the *Q*-value of the reaction and on the angular momentum of the transferred nucleons in the initial and final nuclei, are satisfied [8]. In case of heavy-ion induced reactions, the angular distributions are bell shaped at incident energies close to the Coulomb barrier. At higher incident energies they display

forward rising and under favorable kinematic conditions they also show oscillations characteristic of the angular momentum transferred [6]. Finally since there are many heavy-ion beams, a great number of reaction channels can be used to produce the same residual nucleus [9].

If a pair of neutrons coupled to angular momentum zero is pre-formed in the projectile, the role of the pairing correlations is enhanced. This is what happens in (t,p) reactions; but nowadays triton beams are limited mainly due to restrictive radioprotection rules in many accelerator laboratories. Among the heavy-ion reactions there are many possibility such as (^{6}He, ^{4}He), (^{14}C, ^{12}C) and (^{18}O,^{16}O). The use of ^{6}He and ^{14}C beams is limited because they are radioactive beams and are characterized by low intensity. The ^{18}O beam is stable and so can be produced with high intensity. In this context the (^{18}O, ^{16}O) reactions are good spectroscopy probe to study the pairing interaction. We have chosen to perform such a reaction on ^{12}C target. The residual nucleus ^{14}C is well known and a vast literature is available as regards the configurations of its excited states [10-11]. Thus the study of the known ^{14}C states via the (^{18}O,^{16}O) reaction is a benchmark to learn about the reaction mechanism.

Another important factor is the incident energy. In fact at energies not for above the Coulomb barrier the angular distribution are sensitive to the angular momentum of the final populated states [9]. For these reasons the experiment was performed at about 3.5 times the Coulomb barrier. Furthermore according to the Brink's matching conditions the probability [8] to transfer $L = 0$ angular momentum is not negligible.

2 Experimental set-up and data reduction

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

Fig. 1: MAGNEX at the INFN-LNS, Catania, Italy.

The outgoing ejectiles were momentum analysed by MAGNEX spectrometer [12] and detected by the focal plane detector FPD. In the data presented in this paper the spectrometer was located at 3 different angular settings, with the spectrometer optical axis centered at θ_{opt} = 8°, 12°, 18° in the laboratory frame. Due to the large angular acceptance of MAGNEX (-0.090 rad, +0.110 rad horizontally, ±0.125 rad vertically in the spectrometer reference frame), this setting covers an angular range of about 3° < θ_{lab} < 24°. The magnetic fields were set in order to focus the ^{16}O ejectiles. Particle identification is achieved through the simultaneous measurement of the position and angle, the energy loss and the residual energy as described in details in ref. [13]. The horizontal and vertical positions and angles of the oxygen ions, measured at the focal plane, are used as input of a 10th order ray-reconstruction of the scattering angle and kinetic energy, based on a differential algebraic method

implemented for MAGNEX [14]. This allows an effective compensation of the high order aberrations of the spectrometer [15-16]. The kinetic energy is then transformed, by the use of relativistic kinematic relations, in Q-value or equivalently in excitation energy $E^* = Q - Q_0$, where Q_0 represents the Q-value for the transfer to the ground states of the residual and ejectile nuclei.

3 Data analysis

The first evidence of the selectivity of the (^{18}O,^{16}O) reaction is the transfer yields. The isotopic yields for the different oxygen isotopes are shown in Fig.2. In order to measure the isotopic yields, the bound and resonance states of ^{14}C populated by (^{18}O,^{16}O) reaction were integrated.

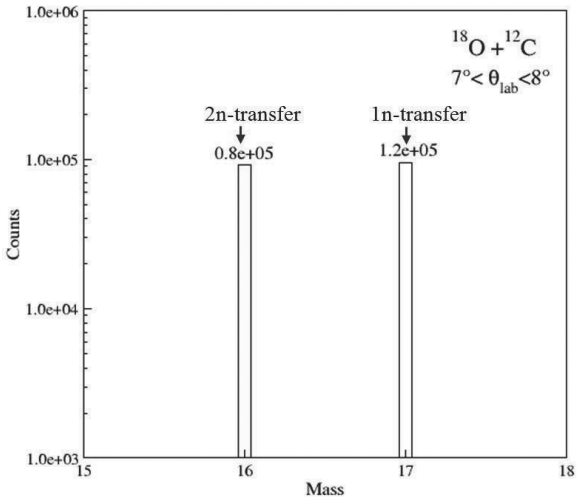

Fig. 2: Yields of ^{17}O, ^{16}O oxygen isotopes for the reactions $^{18}O + ^{12}C$.

The striking results is that the two-neutron transfer process appears as probable as the one-neutron removal. This unexpected enhancement of ^{16}O ejectiles suggests that in the two-neutron removal process there is a relevant contribution from the direct transfer of the neutron pair, and not only a independent transfer (second order process). In fact, if the contribution from the sequential transfer of the two neutrons is dominant a transition amplitude given by the product of two independent terms is expected. Consequently the experimental yields for two-neutron transfer should be much lower than the one-neutron one.

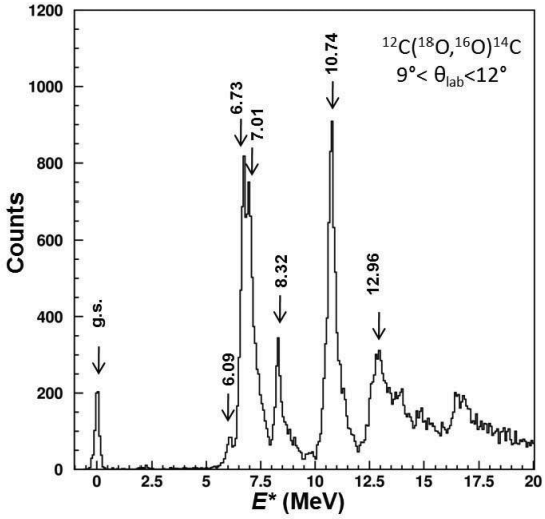

Fig. 3: Spectrum of ^{14}C the reconstructed excitation energy for $9° < \theta_{lab} < 12°$. The isolated peaks are labelled with the relative excitation energy.

A preliminary ^{14}C *Q*-value spectrum is shown in Fig. 3. Several bound and resonant states are observed and identified. All the labeled ^{14}C states have been observed by (t,p) [11] and other heavy-ion reactions [10]. In a tightly bound nucleus, as the ^{12}C, two-neutron transfer reactions can populate both single particle ($^{13}C_{gs}$ + n) and cluster states ($^{12}C_{gs}$ + 2n). The former definitely requires a mechanism of uncorrelated transfer of two neutrons, where the neutron pair in the initial ^{18}O ground state is broken. It is possible to observe, in the spectrum of Fig. 3, that the most populated states have a well known structure described by a two-neutron cluster coupled to the ^{12}C core. For example the states 7.01 and 10.74 MeV have a configuration $\left|\left[(^{12}C_{gs})^{0^+} \otimes (1d_{5/2}, 2s_{1/2})^{2^+}\right]^{2^+}\right\rangle$ and $\left|\left[(^{12}C_{gs})^{0^+} \otimes (1d_{5/2}, 2s_{1/2})^{2^+}\right]^{2^+}\right\rangle$ respectively [10]. This is an important indication of the dominance of the direct one-step nature of the transfer and the minor role of the two-step dynamics.

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