States of ^{15}C via the (^{18}O,^{16}O) reaction

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Abstract
A study of the ^{15}C states was pursued in 2008 at the Catania INFN-LNS laboratory by the ^{13}C(^{18}O,^{16}O)^{15}C reaction at 84 MeV incident energy. The ^{16}O ejectiles were detected at forward angles by the MAGNEX magnetic spectrometer. Thanks to an innovative technique the ejectiles were identified without the need of time of flight measurements.
Exploiting the large momentum acceptance (25%) and solid angle (50 msr) of the spectrometer, the ^{15}C energy spectra were obtained with a quite relevant yield up to about 20 MeV excitation energy. The application of the powerful technique of the trajectory reconstruction did allow to get an energy resolution of about 250 keV FWHM, limited mainly by straggling effects. The spectra show several known low lying states up to about 7 MeV excitation energy as well as two unknown resonant structures at about 11.4 and 13.5 MeV. The strong excitation of these latter together with the measured width of about 2 MeV FWHM could indicate the presence of collective modes of excitation connected to the transfer of a correlated neutron pair.

1 Introduction

The ^{15}C nucleus is a neutron rich system which has stimulated an increasing spectroscopic interest in the years (see [1-3] and reference therein). A simple representation of the low lying states with positive parity can be established within the 1p-2h space, i.e. a sd-shell neutron coupled to the ^{14}C ground state. Differently for the negative parity states, where the 2p-3h space with the inclusion of the supplemental hole in the p-shell, is necessary. A detailed study of both kind of excitation has been done in the past by transfer reactions [1-2]. In addition a clear evidence of the effect of the core polarisation has been found in charge exchange reactions by the appearance of Fano resonances at about 8.4 MeV excitation energy [3]. With the present we want to present a new attempt to study the ^{15}C spectra by the use of the (^{18}O,^{16}O) transfer reaction at 84 MeV. It is known that, at incident energies about 7.5 times the Coulomb barrier the angular distributions of multi nucleon transfer reactions are sensitive to the details of the final populated states [4-5]. In addition under these conditions, according to the Brink's energy and angular momentum matching conditions [6], one expects to excite significantly states with $L = 0$, 2 and 4.

2 The experiment

The experiment has been performed in two steps, first in January 2008 and after in March 2009, at the INFN-LNS Laboratory of Catania. In the first run a restricted angular range between 18° and 40° in the CM reference frame was covered. In the second such range was enlarged between 9° to 50° and a supplemental target of ^{12}C was used. In this manuscript we refer to the first run, being the analysis of the second still under way.

The ^{18}O beam bombarded a 140 μg/cm^2 self supporting ^{13}C target at 84 MeV incident energy. The Oxygen isotopes produced in the collisions were detected by the MAGNEX spectrometer with the purpose to study the structure of ^{14}C, ^{15}C and ^{16}C nuclei via the (^{18}O,^{17,16,15}O) multi-neutron transfer reactions. The magnetic fields were set in order to accept the Oxygen ions with charge between 6^+ to 8^+ at the maximum kinetic energy. These were identified by the simultaneous measurement of their position along the focal plane and their residual energy on the silicon detector hodoscope. In Fig.1 an example of the capabilities of the instrument to identify the ejectiles is shown for this reaction. This result indicates that, for many cases the particle identification can be successfully obtained without the standard measurement of the time of flight as discussed in ref. [7].

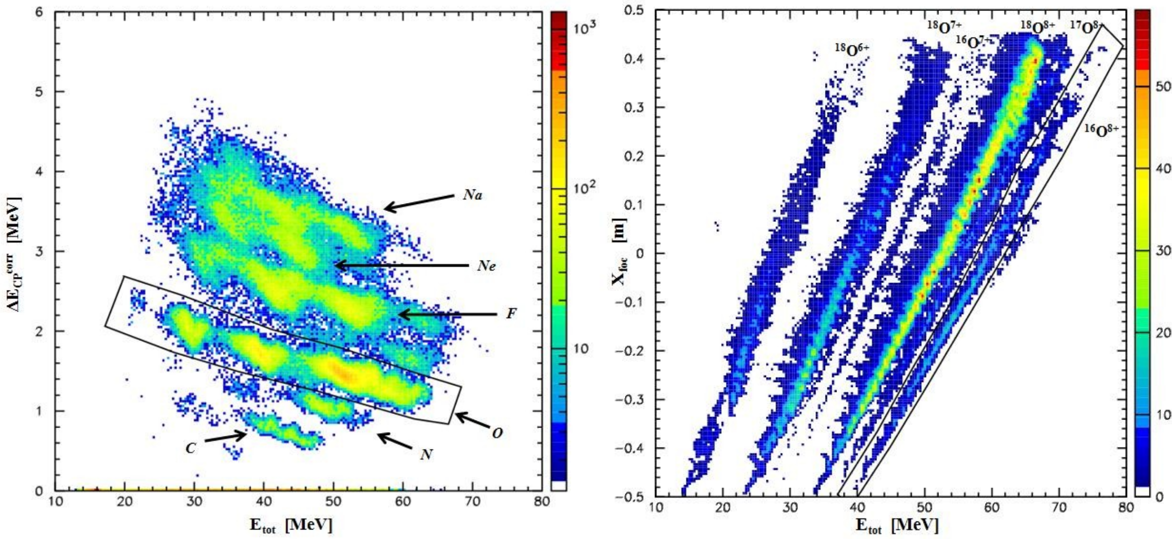

Fig.1: In the left panel the measured energy loss is shown versus the kinetic energy. Different ions are identified by comparison with loci expected from kinematics and energy loss calculations. The selection condition for the Oxygen ions is also drawn. In the right panel the focal plane position is correlated with the kinetic energy for the gated Oxygen ions. Different isotopes and charge states are identified. The selection condition for the $^{16}O^{8+}$ ions is also drawn.

After gating on the $^{16}O^{8+}$ ejectiles, the horizontal and vertical positions and angles at the focal plane are analyzed, thus providing the constraints for the application of the high order algorithms of trajectory reconstruction, implemented in the spectrometer (see [7-8] and reference therein). This procedure does allow for the reconstruction of interesting physical quantities like the scattering angle and the excitation energy of the target residual. An example of bi-dimensional histogram correlating these quantities is shown if Fig.2. In the plot several vertical lines are evident, especially at low excitation energy. These indicate the population of discrete states and narrow resonances of the ^{15}C. One should also note the obtained independence of the reconstructed excitation energy from the scattering angle. By projecting the same data on the abscissa, as done in Fig.3, one gets a closer inspection of the energy of these states. Several peaks are recognized as due to transitions to known states of ^{15}C, namely the ground and states at excitation energy of 0.74, 3.1, 4.22, 4.66, 6.84 and 7.35 MeV. Deviations between the measured energies and the known ones are within 30 keV. Two broad resonances are observed with energies centered at about 11.4 and 13.5 MeV and FWHM of 2 and 2.5 MeV, respectively. These are unknown from literature and represent an interesting result of the experiment.

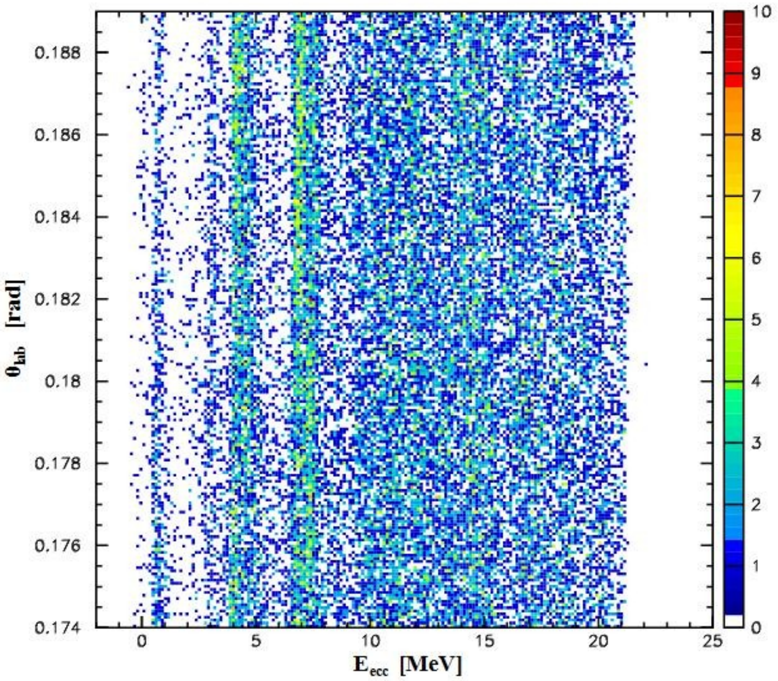

Fig.2: Bi-dimensional spectrum of the reconstructed laboratory angle versus the reconstructed ^{15}C excitation energy for the selected $^{16}O^{8+}$ ions , in the angular range $0.174 < \theta_{lab} < 0.189$ rad.

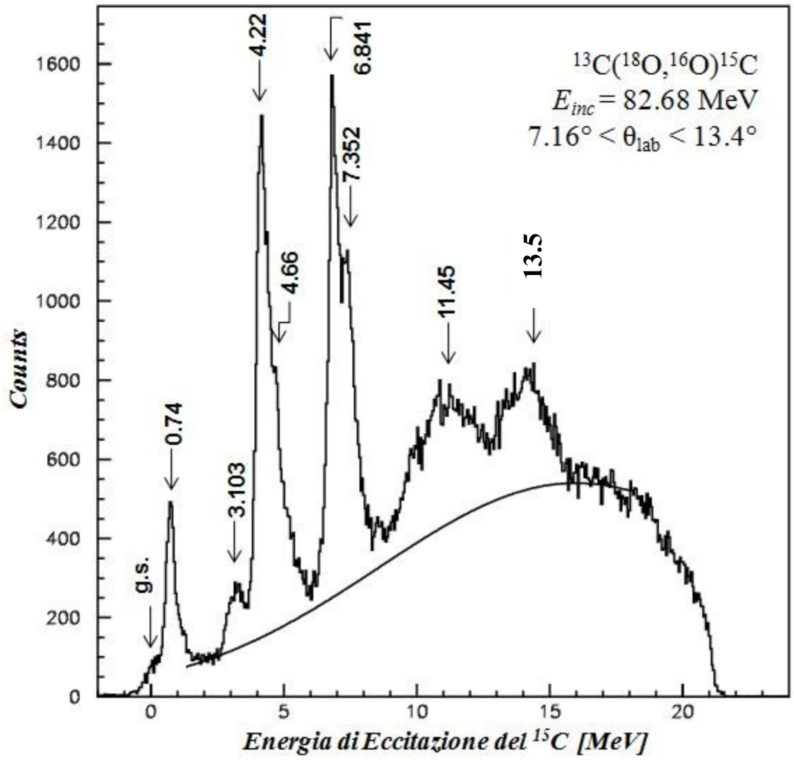

Fig.3: One-dimensional spectrum of the reconstructed ^{15}C excitation energy for the selected $^{16}O^{8+}$ ions , in the angular range $7.16° < \theta_{lab} < 13.4°$. The solid line is only intended to guide the eye.

In Fig.4a the angular distributions of the resonance at 11.4 MeV is compared with that of the $1/2^-$ resonance at 3.03 MeV, which is almost a pure L = 0 transition from the $1/2^-$ ^{13}C ground state [1-2]. Similarly in Fig.4b the same comparison is done with the angular distribution for the L = 3 transition to the $5/2^+$ bound state at 0.74 MeV. A similar behavior is observed between the transition to the 11.4 MeV resonance and the L = 0 one, while deviations are observed with the L = 3 one, at least as regards the slope of the curves. Similar deviations are observed in the comparison with the L = 4 transitions to the $7/2^-$,$9/2^-$ states at 6.84 and 7.35 MeV. As regards the resonance at 13.5 MeV it behaves exactly as the one at 11.4 MeV, thus indicating that perhaps the physical origin of these modes is the same. Taking all of this into account one can infer that the L = 0 transfer seems to be the most likely angular momentum transfer for the population of the resonances at 11.4 and 13.5 MeV.

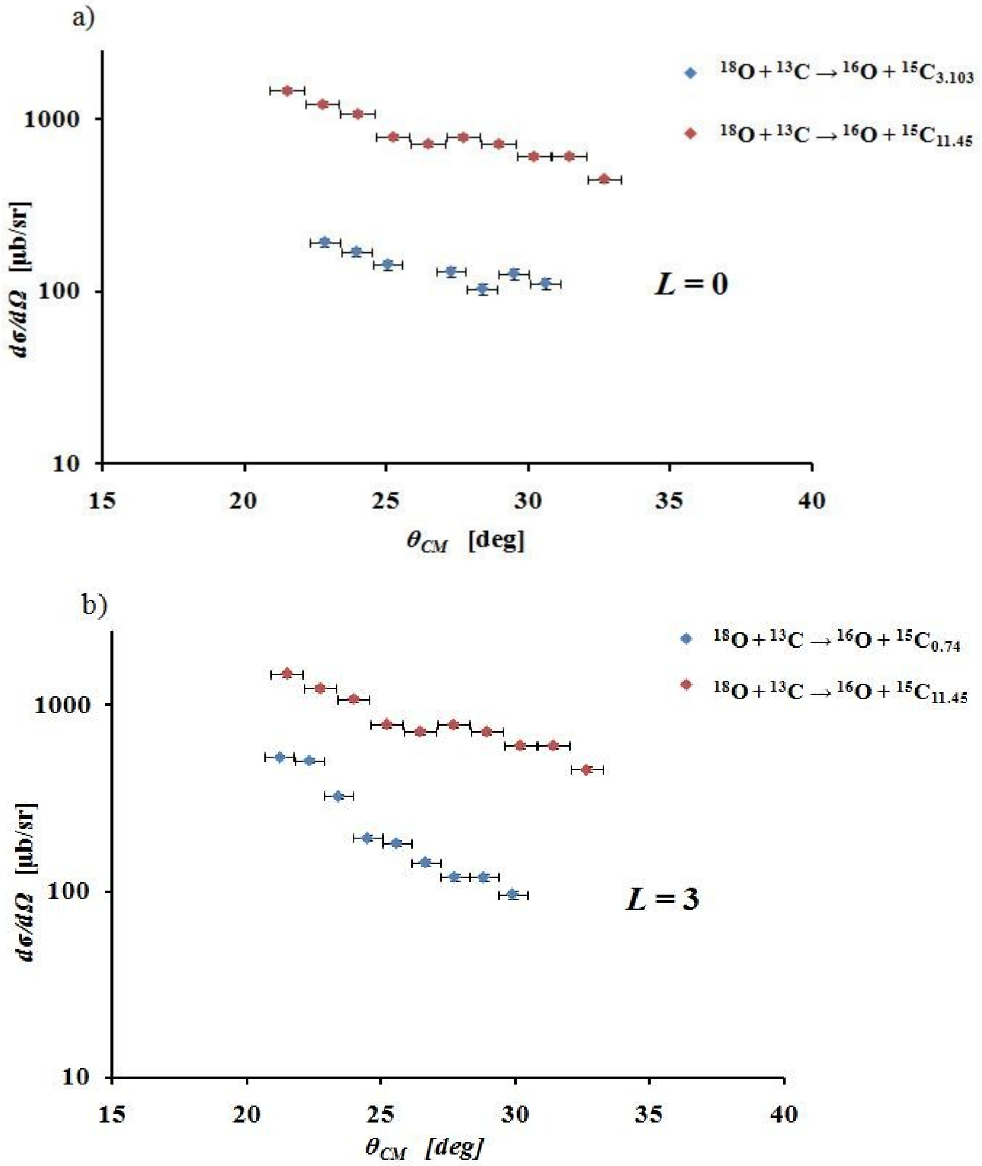

Fig.4: a) Comparison of the measured angular distributions for the transition to the resonance at E_x = 11.45 MeV and at E_x = 3.103 MeV (L = 0). b) Comparison of the measured angular distributions for the transition to the resonance at E_x = 11.45 MeV and to the bound state at E_x = 0.74 MeV (L = 3).

It is also interesting to note in Fig.4a that the cross section for the resonances at 11.4 and 13.5 MeV are about one order of magnitude larger than that at 3.1 MeV, clearly showing that a large amount of the *L* = 0 strength is exhausted in the former. Since the state at 3.1 MeV is an almost pure 2p-1h state, one can conclude about the collective nature of these resonances.

To summarize the dominance of the two neutron transfer mechanism compared to the single neutron transfer has been observed. This indicates the dominance of the pair transfer compared to the second order process of uncorrelated transfer of two neutrons in such experimental conditions. In addition it looks like that a collective degree of freedom has been stimulated by the pair transfer mechanism. The preliminary analysis of the data of the second experiment seems to confirm all of the main features discussed in this manuscript.

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