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2011 J. Phys.: Conf. Ser. 312 092020

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Two-Neutron Excitations in light nuclei via the ($^{18}\text{O}, ^{16}\text{O}$) reaction at 84 MeV

M.Cavallaro^b, F.Cappuzzello^{a,b}, D.Carbone^{a,b}, A.Cunsolo^{a,b}, A.Foti^{a,c}, S.Tudisco^b, M.Bondi^{a,b}, G.Santagati^{a,b}, G.Taranto^{a,b}, R.Chen^{a,d}, R.Linares^{a,e}, F.Azaiez^f, S.Franchoo^f, M.Niikura^f, J.A.Scarpaci^f

a. Dipartimento di Fisica e Astronomia, Università degli Studi di Catania, Catania, Italy

b. Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali del Sud, Catania, Italy

c. Istituto Nazionale di Fisica Nucleare – Sezione Catania, Italy

d. Institute of Modern Physics, CAS, Lanzhou, PRC

e. Instituto de Fisica, Universidade de Sao Paulo, Sao Paulo, Brazil

f. CNRS-IN2P3, Institut de Physique Nucléaire d'Orsay, Orsay, France

Corresponding author e-mail address: manuela.cavallaro@lns.infn.it

Abstract. A study of light neutron rich nuclei was pursued at the Catania INFN-LNS laboratory by the ($^{18}\text{O}, ^{16}\text{O}$) reaction at 84 MeV incident energy on ^9Be , ^{11}B and ^{13}C targets. The ^{16}O ejectiles were detected at forward angles by the MAGNEX magnetic spectrometer. The energy spectra of ^{15}C show several known low lying states up to about 7 MeV excitation energy as well unknown resonant structures at higher excitation energy. 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. Similar features characterize the energy spectra of the ^{11}Be and ^{13}B nuclei.

1. Introduction

Light neutron rich nuclei are ideal systems to study the evolution of the nuclear structure from the β stability valley towards the driplines. From an experimental point of view such nuclei can be accessed via multi neutron transfer reactions using intense stable beams, thus allowing the collection of accurate and statistically rich datasets. From the theoretical point of view the description of these nuclei represents a crucial benchmark to probe advanced microscopic theories of nuclear structure beyond the mean field approximation and toward the ambitious goals of “ab initio” approaches.

As an example the ^{15}C nucleus is a neutron rich system which has stimulated an increasing interest in the years (see [1-3] and reference therein). The low lying states with positive parity can be described within the 1p-2h space, i.e. a sd-shell neutron coupled to the ^{14}C ground state. Instead for the negative parity states 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 by charge exchange reactions by the appearance of Fano resonances at about 8.4 MeV excitation energy [3]. In this paper a new attempt to study the ^{15}C spectra by the use of the ($^{18}\text{O}, ^{16}\text{O}$) transfer reaction at 84 MeV is presented. At this incident energy (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, according to the Brink's energy and angular momentum matching conditions [6], one expects to excite significantly states with $L = 0, 2$ and 4. Particularly interesting are the $L = 0$ transitions since these are the only ones that could excite the

Giant Pairing Vibrations (GPV) predicted in the seventies by Broglia and Bes and never proved experimentally [7].

Similar arguments hold for the ${}^9\text{Be}({}^{18}\text{O}, {}^{16}\text{O}){}^{11}\text{Be}$ and for the ${}^{11}\text{B}({}^{18}\text{O}, {}^{16}\text{O}){}^{13}\text{B}$ reactions at the same incident energy. Despite of the strong interest in the structure of ${}^{11}\text{Be}$ and ${}^{13}\text{B}$ nuclei, in this paper the results for these latter reactions are presented just in connection with those of the ${}^{15}\text{C}$.

2. The experiment

The ${}^{18}\text{O}$ beam was accelerated by the Tandem Van der Graaff accelerator of the INFN-LNS at 84 MeV incident energy. Thanks to a collimation system a spot size of about 1.2 mm (horizontal) \times 2.4 mm (vertical) was obtained on the target, with an angular divergence of about 1 mr in both vertical and horizontal direction. The beam intensity was typically about 80 enA. Different targets were used in the experiment; a $50 \mu\text{g}/\text{cm}^2$ self supporting ${}^{13}\text{C}$ target 99% enriched, a $114 \mu\text{g}/\text{cm}^2$ ${}^9\text{Be}$ target mounted on a $6 \mu\text{g}/\text{cm}^2$ collodion baking and a $33 \mu\text{g}/\text{cm}^2$ ${}^{11}\text{B}$ target on formvar $4 \mu\text{g}/\text{cm}^2$. Supplemental runs with a ${}^{12}\text{C}$ target of $50 \mu\text{g}/\text{cm}^2$ were done in order to estimate the background due to ${}^{12}\text{C}$ impurities in the targets.

The Oxygen isotopes produced in the collisions were momentum analyzed by the MAGNEX spectrometer and detected by the Focal Plane Detector (FPD) [8]. 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. Such technique has been recently shown to allow a clear identification of the different detected ions with a mass resolution as high as 1/160 [9].

Once the ${}^{16}\text{O}^{8+}$ ejectiles are selected, 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 [10-11] and reference therein). This procedure does allow 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 in Fig.1. In the plot several vertical lines are clearly visible, especially at low excitation energy. These indicate the population of discrete states and narrow resonances of the ${}^{15}\text{C}$. One should also note the obtained independence of the reconstructed excitation energy from the scattering angle.

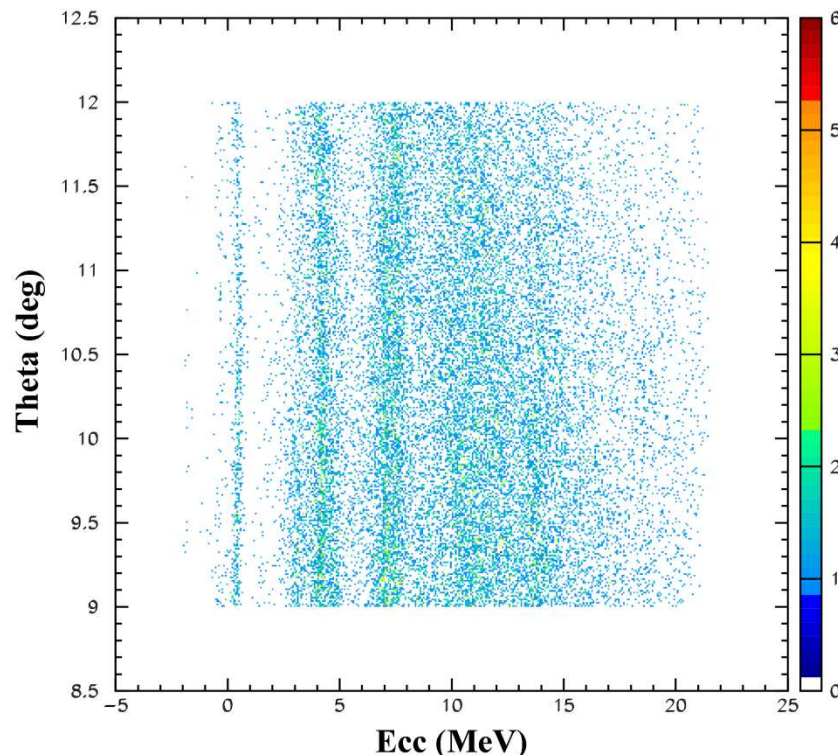


FIGURE 1. Bi-dimensional spectrum of the reconstructed laboratory angle versus the reconstructed ${}^{15}\text{C}$ excitation energy for the selected ${}^{16}\text{O}^{8+}$ ions, in the angular range $9^\circ < \theta_{lab} < 12^\circ$.

By projecting the same data on the abscissa, as done in Fig.2, 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, 3.10, 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 about 2 and 1 MeV, respectively. These are unknown from literature and represent an interesting result of the experiment.

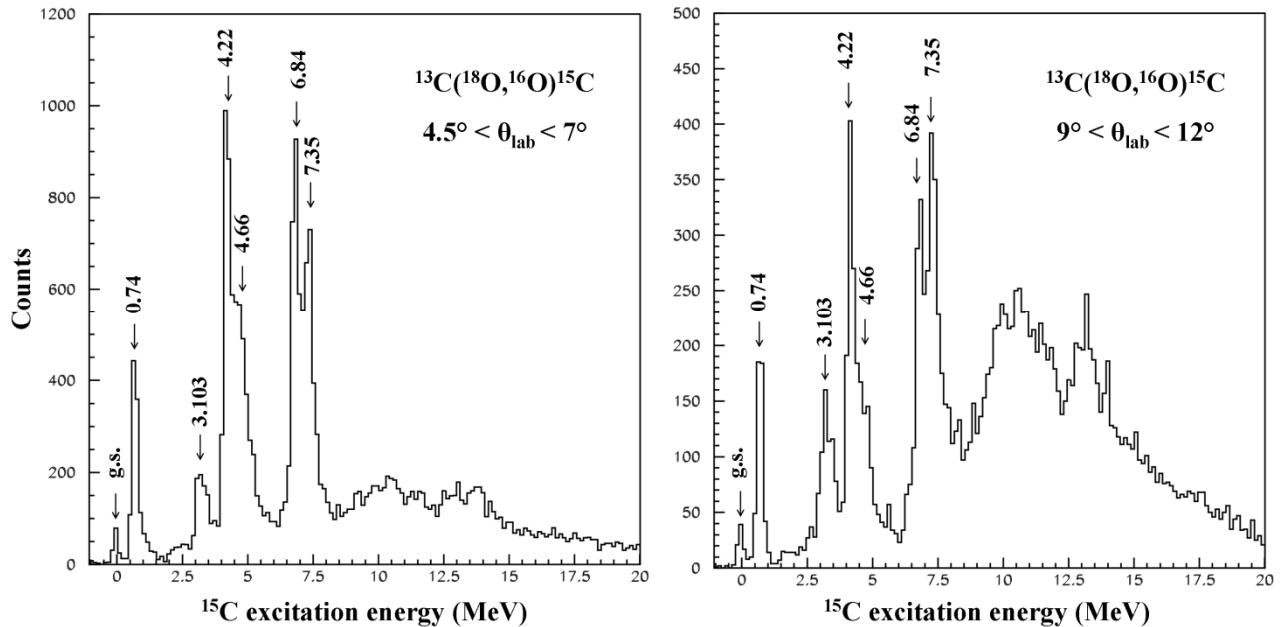


FIGURE 2. Panel a): One-dimensional spectrum of the reconstructed ^{15}C excitation energy for the selected $^{16}\text{O}^{8+}$ ions, in the angular range $4.5^\circ < \theta_{lab} < 7.0^\circ$. Panel b): Same spectrum in the angular range between $9.0^\circ < \theta_{lab} < 12.0^\circ$. The two spectra have been measured under the same experimental conditions and the same integrated charge.

A closer inspection to Fig.3 shows that at different angles the relative population of the ^{15}C states changes, as one expects due to the different angular momentum transferred in the reaction for the different states (see ref. [1,2]). In particular one notices that between $9.0^\circ < \theta_{lab} < 12.0^\circ$ the portion of spectrum between 9 and 18 MeV is more excited relative to the most excited states with $L \neq 0$ below 9 MeV. Similar behavior is observed for the resonant state at 3.10 MeV, which is known to be populated by a pure $L = 0$ transition [1-2]. In the view of the precise determination of the experimental angular distributions, which are presently under way, this could give an indication of the $L = 0$ nature of the transition to the observed resonances at higher excitation energy, which could confirm a previous indication obtained with much less statistics and published in ref [12-13]. Work is in progress to give more detailed and accurate results about this crucial point, which could reveal the excitation of the *GPV* mode in this experiment.

In Fig.3 some results of the runs on ^9Be and ^{11}B targets are shown together with the measured background due to the ^{12}C impurity in the targets. In the ^{11}Be spectrum the ground and the known states at 0.32, 1.78, 2.69, 3.89, 3.96, 5.24 and 6.72 MeV are significantly populated together with a broad structure between 7.5 and 10 MeV not observed in other experiments. In this sense a similarity with the case of ^{15}C is observed, which is strengthened by the comparison with the ^{13}B spectrum. In fact also in this latter case one observes several peaks corresponding to transition to known bound and resonant states and a broad structure between 8 and 12 MeV. Another interesting aspect of the ^{11}Be data is the missing of the high spin states observed in ref [14-15] up to about 22 MeV and connected to a rotational band built on the 3.96 MeV state. This fact seems to confirm the low angular momentum transferred under these experimental conditions. Nevertheless only after an accurate treatment of the different sources of background in the spectra, including the break-up contribution to the measured ^{16}O yields, and after the extraction of the angular distributions one can draw conclusive arguments.

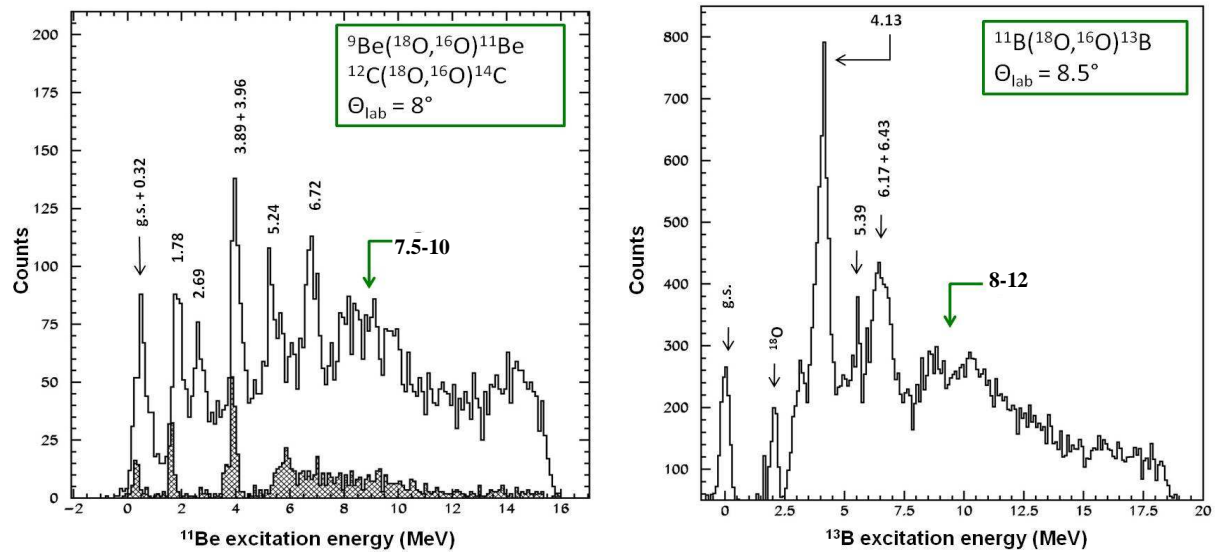


FIGURE 4. Panel a): one-dimensional spectrum of the reconstructed ^{11}Be excitation energy for the selected $^{16}\text{O}^{8+}$ ions, at $\theta_{\text{lab}} = 8.0^\circ$. The dashed histogram represent the estimated background due to the ^{12}C impurities in the target. Panel b): one-dimensional spectrum of the reconstructed ^{13}B excitation energy for the selected $^{16}\text{O}^{8+}$ ions, at $\theta_{\text{lab}} = 8.5^\circ$. In the spectrum the background due to the ^{12}C impurities in the target has been subtracted.

To summarize the response of light nuclei to the excitations induced by the two-neutron transfer operators has been studied via the $(^{18}\text{O},^{16}\text{O})$ reaction above the Coulomb barrier. Several known bound and resonant states of ^{11}Be , ^{13}B and ^{15}C have been populated as well as unknown broad resonances at higher excitation energy that could reveal the appearance of collective motions connected to the transfer of a pair in the nuclei. The study of the angular distributions and of the different component of the continuous background will be necessary to confirm such a conclusion.

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