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(^{18}O,^{16}O) Two-Neutron Transfer Reactions For Spectroscopic Studies

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Abstract. A systematic study of the response of different nuclei to the (^{18}O,^{16}O) two-neutron transfer reaction at 84 MeV incident energy was pursued at the INFN-LNS in Catania (Italy). The experiments were performed using several solid targets from light (^{9}Be, ^{11}B, ^{12,13}C, ^{16}O, ^{28}Si) to heavier ones (^{58,64}Ni, ^{120}Sn, ^{208}Pb). The ^{16}O ejectiles were detected at forward angles by the MAGNEX magnetic spectrometer and identified without the need of time of flight measurements. Exploiting the large momentum (≈ 25%) and angular (50 msr) acceptance of the spectrometer, energy spectra were obtained with a relevant yield up to about 20 MeV excitation energy. A common feature of the light nuclei spectra is the strong population of states with well known configuration of two-particle over a core and the appearance of unknown resonant structures in the continuum. These latter can reveal the excitation of a collective mode connected with the transfer of a pair. For the heavier nuclei as ^{66}Ni a completely different behaviour is observed indicating the presence of more dissipative processes in the reaction mechanisms that hide the spectroscopic information.

Keywords: transfer reactions; magnetic spectrometer.

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INTRODUCTION

Two-neutron transfer reactions are useful tools to study the structure of atomic nuclei thanks to their strong selectivity to specific modes of nuclear excitation and their role in emphasizing n-n correlations such as the pairing force [1-3].

Moreover the detailed description of these transfer reactions could provide useful information to the competition between one- and two-step mechanisms in the two-neutron transfer channel. In the extreme case of very strong pairing correlation, the one-step mechanism is expected to prevail, instead, the two-step sequential process

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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.

Normally the transfer of a cluster takes place when light projectiles as for example tritons are used and the reaction products are detected at forward angles. When heavier projectiles are dealt with, the situation typically becomes more involved. However, in particular projectile-target systems and under specific energetic conditions, one can demonstrate that the correlation between the transferred nucleons could be strong and the one-step mechanism prevail. In such cases even heavy-ion transfer reactions as the (^{18}O,^{16}O) can be used as valuable spectroscopic tools.

THE EXPERIMENT AND THE DATA-REDUCTION

An experimental campaign was performed at the INFN – LNS. The ^{18}O beam, delivered by the Tandem Van der Graaff accelerator at 84 MeV total incident energy, was impinging on different solid targets inside the MAGNEX scattering chamber. In the present paper only the results related to the use of ^{9}Be, ^{11}B, ^{12}C and ^{64}Ni target will be presented. The ^{16}O ejectiles were momentum analyzed by the MAGNEX spectrometer [4, 5] and detected by its Focal Plane Detector (FPD) [6, 7, 8]. In the different experimental runs, the optical axis of the spectrometer was centred at the laboratory angles θ_{opt} = 6°, 12°, 18°, 24°. In all the runs the ejectiles trajectory were accepted between -5.2° and +6.3° in the horizontal direction and ± 7.0° in the vertical, with respect to the optical axis. In such a way an angular range between 3° and 30° was measured in the laboratory frame, with overlaps of about 6° between two contiguous sets of measurements.

The FPD was filled with 99.95% pure isobutane at 7 mbar pressure. A voltage of -1100 V was applied to the cathode while the multiplication wires were supplied with +650 V in order to maintain a proportional regime with a gain factor of about 200. In such working conditions the FPD allows to cleanly identify the detected ions in atomic (Z) and mass (A) number and electric charge (q), and to precisely measure the horizontal and vertical impact position (X_{foc}, Y_{foc}) and direction (θ_{foc}, ϕ_{foc}) of the ions trajectory in the focal plane. Such results have been described in similar experimental conditions in Ref. [9].

A transport map that describes the evolution of the phase-space parameters from the target point to the focal plane has been built [10, 11] thanks to a sophisticated technique based on the formalism of differential algebra [12] implemented in the COSY INFINITY program [13]. Such a technique allows calculating the map up to high order without long ray-tracing procedures. In addition it makes possible to invert the transport equations in order to get the initial coordinates from the measured final ones. The initial parameters extracted from the solution of the inverse equation are directly related to the physical quantities of interest in a typical nuclear reaction analysis, as the modulus of the ion momentum and the scattering angle.

Mass identification is achieved thanks to the simultaneous measurement of the horizontal position at the focal plane X_{foc} and the residual energy E_{resid} of the detected ions. The standard $\Delta E - E$ method is used for the Z identification with a resolution $\Delta Z/Z$ = 1/48. In Ref. [14] it has been shown that one can obtain in this way a clear identification of the detected ions with a mass resolution as high as $\Delta A/A$ = 1/160. An example of application of such an identification technique is shown in Fig. 1 for the ^{18}O + ^{9}Be reaction at 84 MeV.

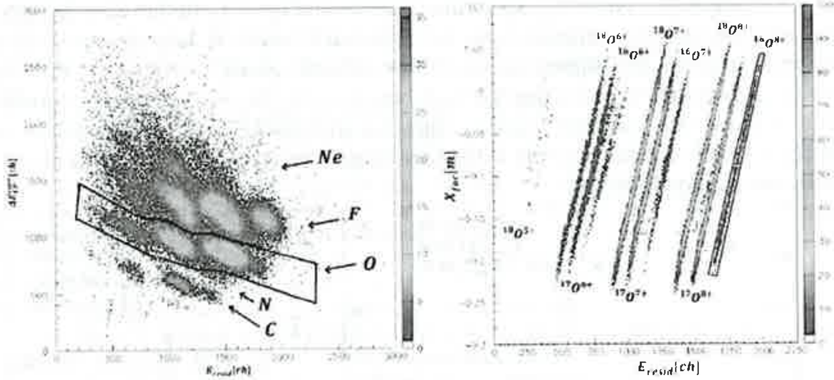

FIGURE. 1 Example of identification plots for the ^{18}O + ^{9}Be reaction at 84 MeV. Left: the energy-loss ΔE^{CP}_{corr} corrected for the measured incident angle at the focal plane is shown against the residual energy E_{resid} measured by the silicon detectors of the FPD. The graphical cut selects the oxygen ions. Right: the horizontal position at the focal plane X_{foc} is plotted against E_{resid} for the data selected by the graphical cut.

FEATURES OF THE SPECTRA

Once the reaction ejectiles are identified, the reconstructed parameters are analysed. In particular the apparent excitation energy $E^{*} = Q_0 - Q$ (where Q_0 is the ground to ground state Q-value) is shown in Fig. 2 for different targets and angular settings.

In Fig. 2 a) the ^{14}C spectrum at 9.5° < θ_{lab} < 10.5° is shown. Several excited states of ^{14}C are populated for which the spin and parity are well known from literature. It is well known that the ground state and the states at 7.01 and 10.74 MeV have dominant configurations with a pair of two neutrons with L = 0, 2 and 4 respectively on a ^{12}C 0^{+} core. It is very interesting to note that this spectrum looks like very similar to those excited with (t,p) reactions [15-17] indicating the strong selectivity of the (^{18}O,^{16}O). Another interesting feature is the appearance of an unknown structure at about 16 MeV [18]. Further studies regarding the nature of such a structure, including the analysis of the angular distribution are foreseen.

The energy spectrum for the ^{9}Be(^{18}O,^{16}O)^{11}Be reaction in the angular range 7.5° < θ_{lab} < 8.5° is shown in Fig. 2 b). 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 at about 8 MeV not observed in other experiments. In this sense a similarity with the cases of ^{14}C is observed, which is strengthen by the comparison with the ^{13}B spectrum shown in Fig. 2 c). In fact also in this latter case one observes several peaks corresponding to transitions 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 absence of the high spin states observed in ref. [19] up to about 22 MeV and connected to a rotational band likely built on the 3.96 MeV state. This fact seems to confirm the low angular momentum transferred under these experimental conditions. Nevertheless only after the extraction of the angular distributions one can draw conclusive arguments.

An example of ^{66}Ni energy spectrum is shown in Fig. 2 d). In this case the spectrum features are sensibly different from the light nuclei ones. A large bump is observed probably due to the superposition of the several peaks expected in this region. However one should notice that for such heavy nuclei the incident energy corresponds to 1.7 times the Coulomb barrier. Thus the dynamical conditions could be rather different compared for example to the light target case, where the energy is about three times the Coulomb barrier.

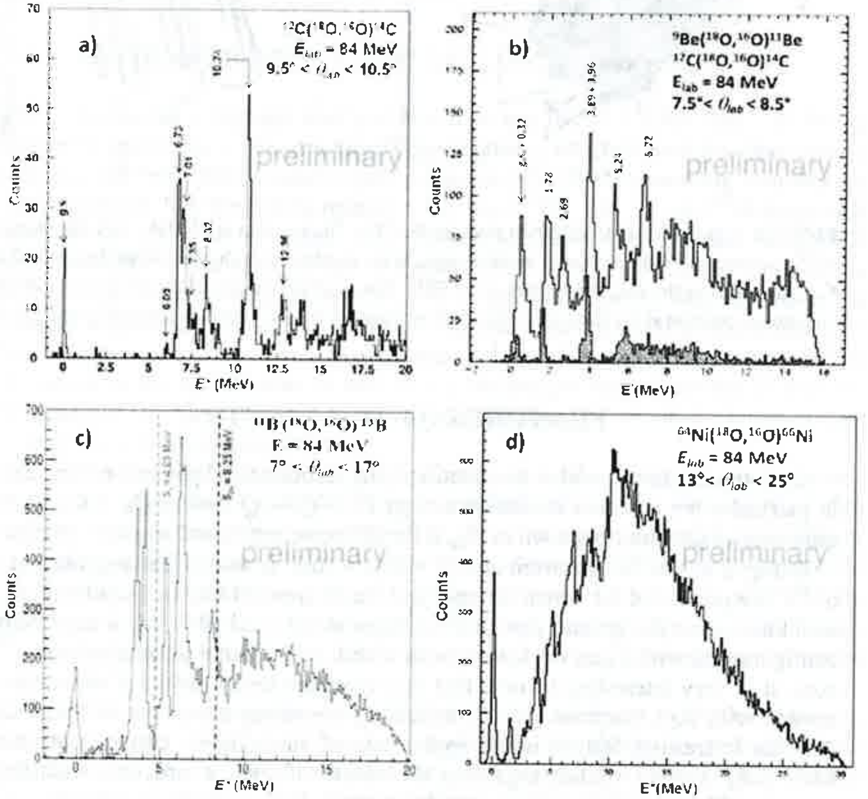

FIGURE 2. One-dimensional spectra of the reconstructed excitation energy of ^{14}C (a), ^{11}Be (b), ^{13}B (c) and ^{66}Ni (d) for the selected $^{16}O^{8+}$ ejectiles emitted in the (^{18}O,^{16}O) reaction at 84 MeV. The contribution due to the ^{12}C impurities in the targets is shown in the hatched histogram in Fig.2 b) and is subtracted in Fig.2 a), c) and d).

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