Study of multi-nucleon transfer reactions with light nuclei

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Abstract. Multi-nucleon transfer reactions are useful tools to populate exotic nuclei, particularly the neutron-rich ones. In this view, two different experiments have been performed employing a stable (^{22}Ne) and a radioactive (^{24}Ne) beam, both impinging on a ^{208}Pb target. The first reaction has been studied using the CLARA-PRISMA-DANTE set-up at Laboratori Nazionali di Legnaro (Legnaro-Italy), while the second reaction was performed at Ganil (Caen-France) employing a SPIRAL radioactive beam of ^{24}Ne. In this case recoils and coincident γ rays were detected with the VAMOS-EXOGAM set-up.

The data show that MNT reactions can selectively populate states of different nature and, therefore, are a good tool to study nuclear structure further away from stability.

Keywords: gamma-ray spectroscopy, multinucleon transfer reactions, radioactive beams
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INTRODUCTION

The spectroscopy of nuclei around mass 20 is particularly interesting since these nuclei are located at the boundaries of the so-called "island of inversion". Important experimental information in this region has been gained using single- and double- step fragmentation [1] and light-particle transfer reactions employing radioactive beams [2, 3].

Multi-nucleon transfer (MNT) and deep-inelastic (DIC) reactions are proved to be useful tools to populate exotic nuclei, particularly the neutron-rich ones. Although these reaction mechanisms have already been extensively exploited in the past years, only recently the availability of efficient spectrometers opens up a variety of new possibilities to study the reaction mechanism itself and to investigate the spectroscopy of medium mass neutron-rich nuclei. In this view, two different experiments were performed employing

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a stable (^{22}Ne) and a radioactive (^{24}Ne) beam.

In this proceeding we present preliminary results from the analysis of both experiments.

THE EXPERIMENTS

The first reaction has been performed using an intense beam (3-4 pnA) of ^{22}Ne at 150 MeV, from the ECR source - positive ion injector (PIAVE), impinging on an enriched 700 μg/cm^2 ^{208}Pb target [4].

The events were measured by means of the CLARA-PRISMA-DANTE set-up. The PRISMA spectrometer [5], placed around the grazing angle for this reaction (estimated to be $\theta_{lab} = 58^\circ$), allows the identification in charge and mass of the reaction products on an event by event basis, through the reconstruction of the individual trajectories. The coupling of PRISMA to the Clover array CLARA [6] allows to detect γ rays emitted in coincidence with the recoils. The 25 Clover detectors are placed around the scattering chamber covering the angles between 98° and 170° with a photopeak efficiency of 3% for 1 MeV γ rays. The addition of DANTE [7], a multi-detector array formed by a variable number of MCP detectors, enables the kinematic reconstruction of part of the events that are outside the PRISMA acceptance, therefore increasing the statistics and allowing the creation of $\gamma - \gamma$ coincidence matrices. In 5 days of data taking a number of 4×10^6 good CLARA-PRISMA coincidences were collected.

The second reaction, performed at Ganil (Caen-France) employed a SPIRAL radioactive beam of ^{24}Ne (at 190 MeV with an intensity of 1.5×10^5 pps) also impinging on a thick ^{208}Pb target [8]. The thickness of the target (10.9 mg/cm^2) was chosen such as to guarantee a counting rate high enough to enable basic gamma-ray spectroscopic information to be obtained. The reaction products were detected in the focal plane of the VAMOS spectrometer [9, 10] which was positioned at the calculated grazing angle for this reaction ($\sim 35^\circ$). The γ rays were detected by the EXOGAM array [11, 12], consisting of 11 segmented germanium Clover detectors, 9 of which had Compton suppression shields. A total of $1.4{*}10^5$ particle-γ coincidences were recorded in 7 days of data taking.

The coupling of a spectrometer to an array of γ-rays detectors allows the study of reaction mechanism dynamics by using the structural information provided by the γ rays. In this way, information on both cross sections and angular momentum population can be deduced from such experiments.

The data show that MNT reactions can selectively populate states of different nature and, therefore, are a good tool to study nuclear structure further away from stability.

PRELIMINARY EXPERIMENTAL RESULTS

The experiment performed in LNL is the most recent and the data analysis is still in progress. In this proceeding we only present the E-ΔE plot (fig. 1) showing the different nuclear species populated in the reaction. The different contours correspond to distinct elements, as indicated in the figure: the reaction populated nuclei ranging from Mg to C,

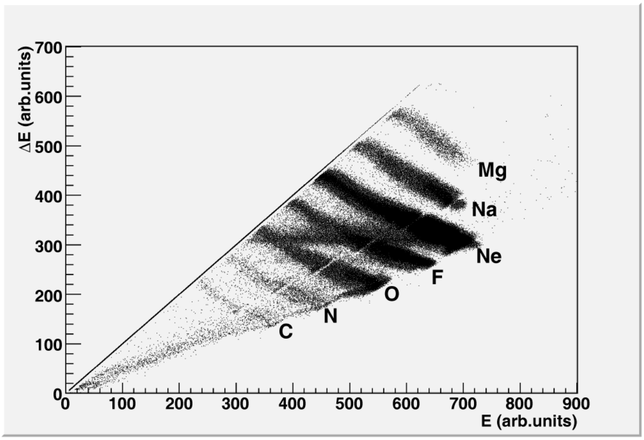

FIGURE 1. *E-ΔE plot showing the isotopes populated in the reaction* $^{22}Ne+^{208}Pb$.

which correspond to the +2p±xn and -4p±xn channels.

The on-going data analysis will allow a detailed analysis of the γ spectra measured in coincidence with every single isotope. Important information on the reaction mechanism can be extracted [13].

The data measured in Ganil are at the moment the most interesting, since we notice a dependence on the population of states of different nature, depending on the scattering angle. This analysis concentrates on γ spectra associated with the most intense neon channels (i.e. ^{24}Ne and ^{25}Ne).

Software conditions on the Q and M/Q of the populated nuclei allow to separate the contributions coming only from $^{25}\mathrm{Ne}^{10+}$. Gates on these nuclei allowed the sorting of isotopically clean γ spectra.

In the following we concentrate on ^{25}Ne which is one of the most intensly populated nuclei with a rich spectrum showing gamma transitions extending up to 3.3 MeV. In particular, the 1.7 MeV $5/2^+ \rightarrow 1/2^+$ transition to the ground state is clearly observed, as the 2.1 MeV $3/2^+ \rightarrow 1/2^+$, 2.35 MeV $7/2^+ \rightarrow 3/2^+$ and 3.3 MeV transition from the direct decay from the $3/2^-$ level to the ground state. There is also a strong peak at 570 keV wich has been identified in β-decay studies [14], even if possibly misplaced in that work.

The transition at 1.7 MeV is a doublet (1.7 and 1.75 MeV), due to the near degeneracy of the $3/2^+$ and $5/2^+$ states. This degeneracy is also predicted by USD calculations and was confirmed by the recent study of ^{25}Ne by nucleon knock-out (see reference [16] and references therein).

In our spectrum we clearly distinguish other two transitions (380 keV and 900 keV) which we are at present not able to locate in the level scheme.

The population of the states as function of the θ angle at target position is also investigated. The gamma spectra were incremented with the requirement that θ was higher or lower than the estimated grazing angle for this reaction (i.e. $\theta < (>) 34°$). The resulting spectra for ^{25}Ne are shown in figure 2. Panel a) of figure 2 shows the spectrum

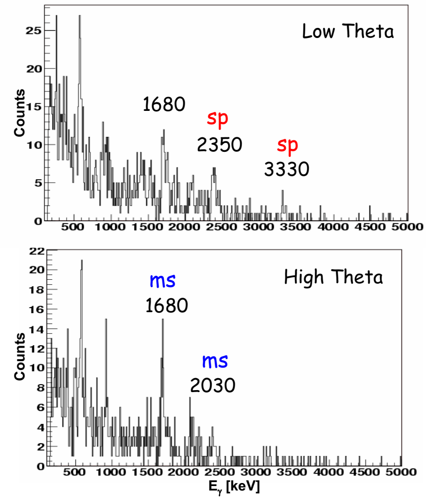

FIGURE 2. γ-ray spectra of ^{25}Ne requiring the condition that $\theta < 34°$ (panel a)) or $\theta > 34°$ (panel b)).

obtained with the condition $\theta < 34°$ (labelled as *'Low Theta'*) and panel b) $\theta > 34°$ (*'High Theta'*). These spectra clearly show different peaks with those present in the *Low Theta* spectrum absent in the *High Theta* cut. The condition of θ being $< 34°$ seems to select mainly transitions from states of single particle character, while the condition $\theta > 34°$ selects states of mixed character.

Moreover the doublet around 1.7 MeV also seems to be populated in different proportions by these conditions.

A similar dependence of the population of single particle and collective states as a function of the recoil angle and γ multiplicity has been reported by the Surrey group using the CHICO detector coupled to GAMMASPHERE, as described in ref.[17, 18].

More quantitative results will be provided after the response function of the VAMOS spectrometer will be unfolded and its combined dependence on angle and momentum examined.

CONCLUSION

In this brief report, preliminary results from the first deep inelastic experiment performed using a radioactive ^{24}Ne beam from SPIRAL have been presented. The presented experiment has been performed with a beam intensity of approximately 1.5*10^5 pps, leading to a total of 10^4 γ-particle coincidences. The data show that, also employing radioactive beams, DIC can selectively populate states of different nature and, therefore, are a good tool to study nuclear structure further away from stability.

This interesting result will be compared by a more recent experiment performed in LNL using a stable ^{22}Ne beam.

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