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Multinucleon transfer reactions studied with the heavy-ion magnetic spectrometer PRISMA

L. Corradi[1,a], A.M. Stefanini[1], S. Szilner[1,6], S. Beghini[2], B.R. Behera[1], E. Farnea[2], A. Gadea[1], E. Fioretto[1], F. Haas[3], A. Latina[1], N. Marginean[1], G. Montagnoli[2], G. Pollarolo[4], F. Scarlassara[2], M. Trotta[5], C. Ur[2], and the PRISMA-CLARA Collaboration

[1] INFN - Laboratori Nazionali di Legnaro, I-35020 Legnaro (Padova), Italy
[2] Dipartimento di Fisica, Università di Padova and INFN, Sezione di Padova, I-35131 Padova, Italy
[3] Institut de Recherches Subatomiques, IN2P3-CNRS-Université Louis Pasteur, F-67037 Strasbourg, France
[4] Dipartimento di Fisica Teorica, Università di Torino and INFN, Sezione di Torino, I-10125 Torino, Italy
[5] INFN - Sezione di Napoli and Dipartimento di Fisica, Università di Napoli, Napoli, Italy
[6] Ruđer Bošković Institute, HR-10 002 Zagreb, Croatia

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Abstract. Recent inclusive measurements on multinucleon transfer reactions reveal important information on the interplay between single-particle and nucleon pair degrees of freedom. More detailed studies are being performed with the new magnetic spectrometer PRISMA, coupled to the CLARA γ-array.

PACS. 25.70.Hi Transfer reactions – 24.10.-i Nuclear reaction models and methods – 23.20.Lv γ transitions and level energies – 29.30.Aj Charged-particle spectrometers: electric and magnetic

1 Introduction

In inclusive measurements performed with time-of-flight and magnetic spectrometers multineutron and multiproton transfer channels have been studied for different systems (see [1] and references therein). The complete identification in nuclear charge, mass and Q-values of the binary reaction products allows to make a significant comparison with coupled channels calculations [2]. In this way, one can investigate the role played by the different degrees of freedom acting in the transfer process, for instance single particle or pair transfer modes. The understanding of these processes is important in view of future research to be done with radioactive beams [3]. Two examples are given below of recently measured systems with closed shell structure.

2 The ^{40}Ca + ^{208}Pb system

The interplay between single particle and pair transfer modes has been investigated [1] with the time-of-flight spectrometer PISOLO [4] at LNL by measuring differential and total cross sections and total kinetic energy loss (TKEL) distributions for multinucleon transfer channels.

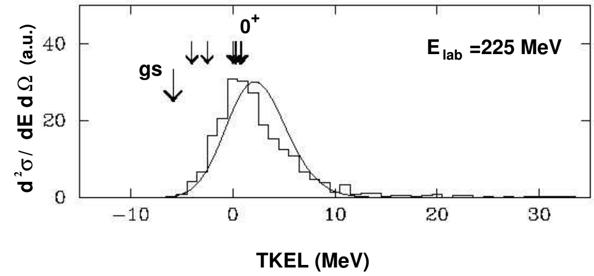

Fig. 1. Experimental (histogram) and theoretical CWKB (curve) total kinetic energy loss distribution of the two neutron pick-up channel. The arrows correspond to the energies of 0^+ states in ^{42}Ca with an excitation energy lower than 7 MeV, gs marks the ground to ground state Q-value.

In the ^{40}Ca + ^{208}Pb system measurements have been recently performed [5] at 3 bombarding energies close to the Coulomb barrier. Figure 1 shows the TKEL distribution at E_{lab} = 225 MeV for the two neutron pick-up (+2n) channel together with calculations performed within the semiclassical Complex WKB (CWKB) theory [1,6]. One sees that this channel has a well defined maximum, which, within the energy resolution of the experiment, is consistent with a dominant population, not of the ground state of ^{42}Ca, but of the excitation region close to 6 MeV. In this region 0^+ states were observed to be strongly populated

[a] Conference presenter; e-mail: corradi@lnl.infn.it

in light-ion reactions and were interpreted as multi (additional and removal) pair-phonon states [7]. Nuclear structure and reaction dynamics studies attribute this behavior to the influence of the $p_{3/2}$ orbital that gives a much larger contribution to the two-nucleon transfer cross section than the $f_{7/2}$ orbital which dominates the ground state wave function. At all bombarding energies one has a very similar behavior [5] and the features of the spectra are well reproduced by theory indicating that the used single particle levels cover the full TKEL spanned by the reaction. The results show that, at least in suitable cases, one can selectively populate specific energy ranges even in transfer reactions with heavy ions, opening the possibility to study multi pair-phonon excitations.

3 The ^{90}Zr + ^{208}Pb system

More detailed experiments able to distinguish between excited states of the transfer reaction products must exploit the full capability of magnetic spectrometers with solid angles much larger than conventional ones and resolutions sufficient to deal with very heavy mass ions. This is possible now with the PRISMA [8] spectrometer that has recently been installed at LNL and is designed for the $A = 100$–200, $E = 5$–10 MeV/u heavy-ion beams of the accelerator complex of LNL. The main features of the spectrometer are its large solid angle 80 msr, wide momentum acceptance ±10%, mass resolution 1/300 via time-of-flight and energy resolution up to 1/1000. PRISMA has also been coupled to the CLARA γ-array [9] consisting of 25 Clover detectors from the Euroball Collaboration. First experiments on grazing collisions between heavy ions have been already performed with different beams. The main goals of these measurements were to investigate the population of neutron-rich nuclei in the $A = 40$–90 mass region by means of multinucleon transfer reactions [10], and to study the dynamics of such transfer processes.

Figure 2 shows an example of spectra very recently obtained in the ^{90}Zr + ^{208}Pb reaction [11] at $E_{\rm lab} = 560$ MeV, with a ^{90}Zr beam accelerated with the ALPI + Tandem complex of LNL at intensities of $\simeq$ 3 particle-nA. This exploratory experiment with PRISMA + CLARA was performed with the main aim of investigating the production of Zr and Sr isotopes for specific Q-values that are close to those where the excitation of pair vibrational modes is expected. As the Zr isotopes span a range from spherical to highly deformed shapes, it will be interesting to investigate into detail the change of the population and decay pattern of specific levels populated via multinucleon transfer reactions. The upper part of fig. 2 shows the mass distributions of Zr isotopes after gating on the nuclear charge $Z = 40$. One observes events corresponding to the pick-up as well as stripping of neutrons. One observes different relative yields in mass spectra for the Zr isotopes, due to the different γ multiplicities for the various multinucleon transfer channels populated in the reaction. The ratio of events in the two spectra for specific masses is consistent with an overall efficiency of a few % of CLARA for γ transitions in the range $\simeq$ 2 MeV. The single coincident γ spectrum for ^{90}Zr has been obtained after Doppler correction for the projectile-like nuclei selected by the spectrometer, taking into account the two-dimentional position determination at the entrance of PRISMA, the ion time of flight and the geometry of the Clover detectors.

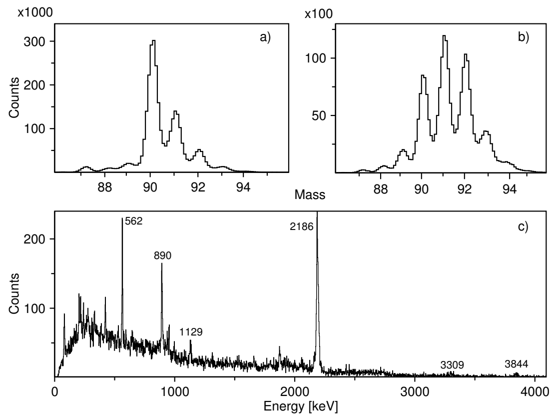

Fig. 2. Panels a) and b): mass distributions for Zr isotopes obtained in the reaction ^{90}Zr + ^{208}Pb at $E_{\rm lab} = 560$ MeV and at the grazing angle $\theta_{\rm lab} = 54°$, without (a) and with (b) γ coincidences. Panel c): γ-ray spectrum of ^{90}Zr, obtained by gating on $Z = 40$ and $A = 90$. The Z information is derived from the ionization chamber array of PRISMA. The peak at $E_\gamma = 2186$ keV corresponds to the lowest $2^+_1 \to 0^+_{\rm g.s.}$ transition in ^{90}Zr.

The determination of the reaction yields for levels populated in the Zr and Sr isotopes will be important for both nuclear structure and reaction mechanism. In particular, detailed comparison with coupled channel calculations can be performed.

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