Study of the Multinucleon Transfer Channels in the 197\(^{197}\)Au+\(^{130}\)Te Reaction through a High-resolution Kinematic Coincidence

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Multinucleon transfer channels, populated in the inverse kinematic reaction 197\(^{197}\)Au+\(^{130}\)Te at Exa=1.07 GeV, were studied by means of a high-resolution kinematic coincidence set-up composed of the large acceptance magnetic spectrometer PRISMA coupled to a new detection system acting as second arm. The comparison of the experimental mass-mass correlation matrix with Monte Carlo simulations allowed us to investigate the role of neutron evaporation in the population of neutron-rich heavy nuclei around A=200.

KEYWORDS: Multinucleon transfer reactions, large acceptance magnetic spectrometer, kinematic coincidence measurements

1. Introduction

The knowledge of the properties of neutron-rich nuclei located along the neutron
closed shell N=126 (the last “waiting point” along the r-path) is of great importance for a better understanding of the r-process nucleosynthesis, leading to the production of heavy elements in the stars, as well as for investigating the shell and shape evolution in this unexplored region of the nuclide chart. Indeed, due to the difficulties in producing these exotic nuclei with sufficient cross sections, experimental information is scarcely available. In order to access this region with stable beams only few reaction mechanisms can be employed while the use of radioactive ion beams (RIB) could require considerably long beam times due to the low beam intensities.

Theoretical calculations performed within different models [1,2] predicted sizeable primary cross sections for the production of neutron-rich heavy nuclei through multinucleon transfer (MNT) processes.

Recently, the multinucleon transfer reaction $^{136}$Xe+$^{198}$Pt reaction at about 8 AMeV [3] was experimentally investigated at GANIL in order to get the production cross sections of neutron-rich heavy nuclei in the Pt-Os region. Due to the experimental difficulties in the direct identification of the heavy partners, a complex iterative procedure was used to reconstruct their production cross sections from the experimental yields and the total kinetic energy loss (TKEL) distributions of the detected light partners. Experimental results proved that MNT process is a suitable mechanism complementary to the fragmentation of heavy projectiles (Pb, U) on light targets [4] at relativistic energies. In particular, the experiment evidenced that the most neutron-rich nuclei are populated in MNT processes involving low excitation energies where the role of secondary processes, such as nucleon evaporation and transfer induced fission, is reduced so that the probability for the primary heavy partner to survive these effects increases.

In order to directly investigate such secondary processes, a kinematic coincidence measurement was carried out at the INFN Laboratori Nazionali of Legnaro (LNL) by using the inverse kinematic reaction $^{197}$Au+$^{130}$Te at the near-barrier energy $E_{lab}$=1.07 GeV. The $^{197}$Au beam was delivered by the PLAVE-ALPI superconducting accelerator complex with an intensity of 1.5 pnA. The use of the inverse kinematics allowed to achieve a high detection efficiency and good mass and nuclear charge resolutions due to forward focusing of the reaction products and, for the present reaction, the higher kinetic energy of both binary partners at forward angles. On the basis of optimum Q-value and nuclear form factor considerations [5, 6], we chose the most neutron-rich Te stable isotope as a target to open the proton pick-up and neutron stripping channels leading to the population of neutron-rich heavy nuclei. The results of the experiment were recently published in a dedicated article [7].

2. PLF and TLF mass identification

The layout of the experimental set-up is shown in Figure 1. The magnetic spectrometer PRISMA [8], acting as main arm of the coincidence set-up, and its focal plane detector were settled in order to select and identify with high resolution the light target-like fragments (TLF). The coincident heavy projectile-like fragments (PLF) were detected through an ancillary detection system, acting as second arm and named NOSE, composed of a Parallel Plate Avalanche Counter (PPAC) followed by an axial field ionization chamber [9]. The trajectory reconstruction of TLFs inside the PRISMA spectrometer was done, on an event-by-event basis, by measuring their position at the entrance (MCP) and at the focal plane (MWPPAC) of the spectrometer and their time of
flight. The nuclear charge identification of TLFs, stopped in the active depth of the transverse field multi-anode ionization chamber (IC) of PRISMA, is obtained by using the E-ΔE technique. This information allows to identify the different atomic charge states transported up to the focal plane and then to construct the TLF mass distribution.

It is worthwhile to mention that in this experiment we chose a rather low bombarding energy (around the Coulomb barrier), in order to reduce the effect of secondary processes having in mind that the transfer yields, especially for proton transfer channels, may be modest, at least one order of magnitude less than those for neutrons. For this reason, we focus here on pure neutron transfer channels.

Figure 2 shows the mass distribution of Te isotopes populated in the reaction. Assuming a pure binary character of the process and imposing the momentum conservation, the mass of heavy PLFs is determined by the measured scattering angles in PRISMA and in NOSE and their time-of-flights taken to cover the distance d ~ 90 cm from the target to the PPAC of NOSE. The PLF mass resolution strongly depends on the resolution on the time-of-flight and is only slightly affected by the angular resolution. The obtained value is ΔA/A ~ 1/40, which means ~ 5 mass units for the Au-like mass distribution.

Combining the information of both arms of the kinematic coincidence set-up, the mass-mass correlation matrix shown in Figure 3 (left) was constructed associating to each light TLF identified in PRISMA the coincident mass distribution of the heavy PLF detected in the second arm. As one can see, the total mass distribution of the heavy partner appears divided in well separated bands in correspondence of the coincident light TLF identified in PRISMA. One can also notice that after the transfer of ~ 3-4 neutrons the centroids of the experimental mass distributions for PLFs (full black circles) begin to deviate from the trend expected for the ones of primary PLFs (empty red circles). The shift between primary and secondary centroids is due to the neutron evaporation.

The experimental results were confirmed by Monte Carlo (MC) simulations, shown in the right panel of Figure 3, incorporating the relevant observables (see caption). They
also evidenced that neutron evaporation, besides shifting the centroids of the mass distributions, enlarges their width as more neutrons are transferred.

3. Summary

The role of neutron evaporation on the final yields of the heavy partners, populated in the multinucleon transfer reaction $^{197}$Au + $^{130}$Te at $E_{\text{lab}} = 1.07$ GeV, has been studied through a kinematic coincidence measurement in which the TLF is identified in PRISMA with high resolution. Experimental results together with MC simulations proved that the used technique is a powerful tool to investigate the effect of secondary processes in transfer reactions. Neutron evaporation starts to play a relevant role only after the transfer of several neutrons, indicating that MNT reactions at near-barrier energies are a suitable mechanism to populate moderately neutron-rich heavy nuclei.

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