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F. Galtarossa(1)(2), L. Corradi(1), S. Szilner(3), E. Fioretto(1), G. Pollarolo(4), T. Mijatović(3), D. Montanari(5), D. Ackermann(6), D. Bourgin(7), S. Courtin(7), G. Fruet(7), A. Goasduff(1), J. Grebosz(8), F. Haas(7), D. Jelavić Malenica(3), S. C. Jeong(9), H. M. Jia(10), P. R. John(5), D. Mengoni(5), M. Milin(11), G. Montagnoli(5), F. Scarlassara(5), N. Skukan(3) N. Soić(3) A. M. Stefanini(1) E. Strano(5), V. Tokić(3), C. A. Ur(12), J. J. Valiente-Dobón(1) and Y. X. Watanabe(9)

(1) *INFN, Laboratori Nazionali di Legnaro - Legnaro, Italy*
(2) *Dipartimento di Fisica e Scienze della Terra, Università di Ferrara - Ferrara, Italy*
(3) *Ruđer Bošković Institute - Zagreb, Croatia*
(4) *Dipartimento di Fisica, Università di Torino and INFN - Torino, Italy*
(5) *Dipartimento di Fisica, Università di Padova and INFN - Padova, Italy*
(6) *GANIL, CEA/DSM-CNRS/IN2P3 - Boulevard Henri Becquerel, Caen, France*
(7) *Institut Pluridisciplinaire Hubert Curien, CNRS-IN2P3, Université de Strasbourg Strasbourg, France*
(8) *The Henryk Niewodniczanski Institute of Nuclear Physics - Krakow, Poland*
(9) *Institute of Particle and Nuclear Studies, High Energy Accelerator Research Organization (KEK) - Tsukuba, Ibaraki, Japan*
(10) *China Institute of Atomic Energy - Bejing, China*
(11) *Department of Physics, Faculty of Science, University of Zagreb - Zagreb, Croatia*
(12) *Horia Hulubei National Institute of Physics and Nuclear Engineering - Bucharest, Romania*

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Summary. — We studied multinucleon transfer (MNT) processes in the ^{197}Au + ^{130}Te at E_{lab}=1.07 GeV system coupling the PRISMA magnetic spectrometer to NOSE, an ancillary particle detector. We constructed a mass correlation matrix associating to each light fragment identified in PRISMA the corresponding mass distribution of the heavy partner detected in NOSE and, through the comparison with Monte Carlo simulations, we could infer about the role of neutron evaporation in multinucleon transfer reactions for the population of neutron-rich heavy nuclei.

1. – Introduction

The study of the properties of neutron-rich nuclei close to the N = 126 shell closure is fundamental to investigate different physical cases and get important information on the process leading to the production of heavy elements in the stars (r-process). The study of these nuclei is hindered by the difficulties in producing them with sufficient cross sections both with stable and unstable beams. In the former case only few reactions can give access to the neutron-rich side of this region of the nuclear chart, in the latter the low beam intensities may require considerably long beam times to perform a detailed spectroscopy study.

Nuclear reaction models [1,2] predict large primary cross sections employing multinucleon transfer reactions. At energies close to the Coulomb barrier the main open channels are neutron pick-up and proton stripping from the light partner, due to optimum Q-value considerations and nuclear form factors [3,4].

In a recent paper [5] the cross sections for the population of neutron-rich nuclei in the Pt-Os region measured in the MNT reaction ^{136}Xe+^{198}Pt were compared with those obtained in the relativistic fragmentation of ^{208}Pb on a Be target [6], showing that MNT reactions are in fact a suitable and complementary mechanism to fragmentation to produce neutron-rich heavy nuclei. In the work heavy nuclei were not directly identified due to the experimental difficulties in reaching the required resolution and the production cross sections could only be reconstructed in a complex iterative way from the measured yields and total kinetic energy loss (TKEL) distributions of the detected light fragments. An important conclusion drawn by the authors is that neutron-rich nuclei are populated in transfer reactions involving low excitation energies, so that the probability for the primary heavy partner to survive the effect of secondary processes, like nucleon evaporation or fission, is increased.

To measure the effect of such competitive processes in a more direct way we performed an experiment at the INFN Laboratori Nazionali of Legnaro (LNL) to study MNT reactions at near-barrier energies in the ^{197}Au+^{130}Te (E_{lab} = 1.07 GeV). The light partner of the reaction was detected with high resolution in the large-acceptance magnetic spectrometer PRISMA [7], while the coincident heavy partner was detected in an ancillary particle detector named NOSE [8]. We chose the most neutron-rich Te stable isotope as a target to open the proton and neutron transfer channels leading to neutron-rich heavy partners. Favorable experimental conditions were achieved by employing inverse kinematics in such a way that both reaction partners could have enough energy for their detection. The results of the experiment were recently published in a dedicated article [9].

2. – Mass identification of light and heavy reaction partners

The layout of the experimental set-up and the kinematics of the reaction are depicted in Figure 1. For the mass identification of the light reaction products in PRISMA one needs to reconstruct their trajectory inside the spectrometer, which is done on an event-by-event basis by measuring their entrance and exit position on the MCP and MWPPAC, respectively, and their time of flight. The nuclear charge is identified using the E-ΔE technique in the ionization chamber, where the ions are stopped. Being the cross sections for proton transfer channels at least one order of magnitude less than those for neutrons, we focus here on pure neutron transfer channels.

To reconstruct the mass of the heavy partner we assume a binary character of the reaction and impose momentum conservation. The mass of the heavy partner is then determined by the measured scattering angles in PRISMA and in NOSE and the time-of-flight taken by particle B to cover the distance d $\sim$ 90 cm from the target to the PPAC of NOSE. The 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 $\Delta A/A \sim 1/40$,

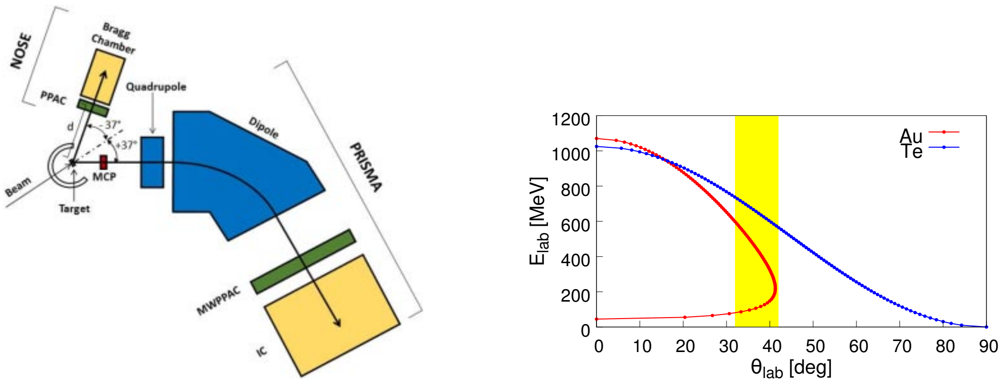

Fig. 1. – (Left) Layout of the set-up used in the study of the ^{197}Au+^{130}Te reaction, with the PRISMA spectrometer set in coincidence with the NOSE detector. Bragg chamber: axial field ionization chamber; PPAC: multiwire parallel-plate avalanche counter of NOSE; MCP: micro-channel plate detector; MWPPAC: parallel-plate detector of multiwire type; IC: ionization chamber of PRISMA. (Right) Kinematics of the elastic channel in the reaction ^{197}Au+^{130}Te at E_{lab}=1.07 GeV in a plot E_{lab} vs θ_{lab}. The yellow band corresponds to the acceptance of the PRISMA spectrometer.

which means $\sim$ 5 mass units for the Au-like mass distribution. The masses of light and heavy reaction partners are shown on the left and right panel of Fig. 2, respectively.

Combining the information of the coincident detectors we could construct the mass-mass correlation matrix of Fig. 3 (left) where the the total mass distribution of the heavy partner appears divided in well-separated bands in correspondence of the coincident light fragment identified in PRISMA. One can notice how after the transfer of $\sim$ 3-4 neutrons the centroids of the experimental distributions (full black circles) begin to deviate from the expected trend of the primary centroids (empty red circles). The shift between primary and secondary centroids is an effect of neutron evaporation.

To get more quantitative information we compared the experimental mass distributions of the heavy partner in correspondence of each Te isotope identified in PRISMA

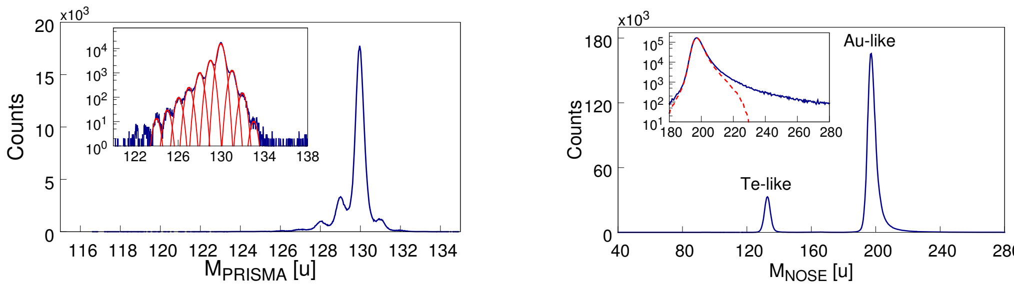

Fig. 2. – (Left) Mass distribution for the Te isotopes obtained after ion trajectory reconstruction in PRISMA. The inset shows the distribution in logarithmic scale with the multigaussian fit used to evaluate the yields of neutron transfer channels. (Right) Mass distribution obtained in NOSE. Te-like and Au-like ions are clearly distinguished. The inset shows the mass distribution of the heavy partner in logarithmic scale without (blue solid line) and with (red dashed line) a gate to exclude energy-degraded events in NOSE.

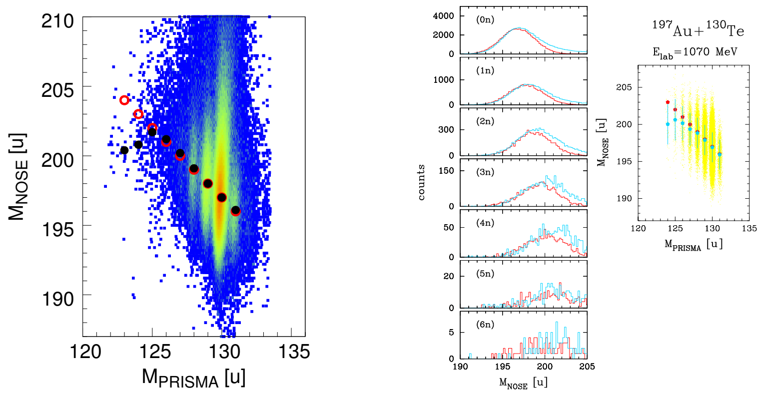

Fig. 3. – (Left) Mass-mass correlation matrix of Te isotopes detected in PRISMA and the heavy partner detected in coincidence with NOSE. The red circles indicate the centroids of the correlated masses of the primary neutron transfer channels, the black dots indicate the experimental centroids as derived from the fits of their projections. (Right) Simulated mass-mass correlation matrix, where the points are the centroids of the primary (red) and actual (green) Au isotope distributions and the green bars represent the standard deviations, together with the comparison between the simulated (red) and experimental (green) mass distributions obtained from the projection of the corresponding mass-mass matrix. The label in each frame indicates the number of neutrons stripped from ^{130}Te.

with Monte Carlo (MC) simulations incorporating the relevant experimental observables (measured cross sections, TKEL distributions, experimental resolution). More details concerning the MC simulations can be found in Ref. [9]. The comparison is shown in the right panel of Fig. 3. One can see that neutron evaporation, besides shifting the centroids of the mass distributions, enlarges their width as more neutrons are transferred.

3. – Conclusions

In this work we presented our method to measure the effect of neutron evaporation in the multinucleon transfer reaction ^{197}Au+^{130}Te at E_{lab} = 1.07 GeV. The employed kinematic coincidence technique where one of the reaction partners is identified with high resolution, in combination with the Monte Carlo simulations, proved to be a powerful tool to investigate the effect of secondary processes in transfer reactions. Neutron evaporation starts to play a relevant role 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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