The $^{197}$Au+$^{130}$Te reaction studied with PRISMA coupled to a new time of flight set-up

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INTRODUCTION

Following the experience gained in the measurements at sub-barrier energies [1, 2] we recently performed an experiment to study the multineutron and multiproton transfer channels in the reaction $^{197}$Au+$^{130}$Te at $E_{lab}$=1070 MeV [3]. The first physics goal was to get the A, Z and Q-value distributions measuring the “light” reaction products and compare final yields with those expected from theoretical models, already successfully applied for lower mass systems [4–7]. In particular, via the 2 proton stripping ($2p$) and 4 neutron pick-up ($4n$) channels one should be able to populate $^{132}$Sn, a benchmark nucleus [8, 9]. The second goal was to compare the yields of the “light” partner with those of the “heavy” one. With neutron rich projectiles proton pick-up and neutron stripping channels open up. For the heavy partner this is reflected in the population “south-east” from the injection point, leading to the neutron rich Pt-Os heavy region. Competitive processes, i.e. evaporation and fission, may significantly shift the final yield to lower mass values and it is therefore important to get information on the yield distributions. The heavy partners are presently receiving peculiar attention. In fact, certain regions of the nuclear chart, like that below $^{208}$Pb or in the actinides, can be hardly accessed by fragmentation or fission reactions, and multinucleon transfer may be a suitable mechanism (if not the only one) to approach those neutron rich areas.

THE FIRST (TEST) MEASUREMENT

In a first test experiment [3], we used a 2 pnA $^{197}$Au beam delivered by the PIAVE+ALPI accelerator complex of LNL onto a $100\,\mu g/cm^2$ $^{130}$Te target with a purity of 99.6%. We detected with PRISMA, at an angle close to the grazing one ($\theta_{lab}$ = 37°, same at this energy for the two partners), projectile-like and target-like ions, setting different magnetic fields for the two kind of ions in two different runs. To get the best possible ion identification, we used inverse kinematics, where both binary partners have high kinetic energy at quite forward angles. Figure 1 shows as an example the matrix mass vs position of the focal plane for Te isotopes, obtained by selecting only one of the atomic charge states. The asymmetric $A/q$ peak distribution is due to the distortion of the ion optics.

Fig. 1. Matrix of mass vs position at the focal plane for Te isotopes detected in PRISMA in the $^{197}$Au+$^{130}$Te reaction at $E_{lab}$=1070 MeV and $\theta_{lab}$ = 37°. The different bands correspond to neutron stripping and pick-up channels. The right side shows the projection on the mass axis. Only one atomic charge state has been selected.

Fig. 2. Matrix of mass over atomic charge state ($A/q$) vs position at the focal plane for Au-like particles detected in the $^{197}$Au+$^{130}$Te reaction at $E_{lab}$=1070 MeV and $\theta_{lab}$ = 37°. The projections on the two axis are also displayed. The asymmetric $A/q$ peak distribution is due to the distortion of the ion optics.
event-by-event reconstruction of the ion trajectory inside the magnetic elements, using two-dimensional entrance and exit positions and time-of-flight [10, 11]. One sees the quality of separation between different masses, allowing to identify neutron stripping as well as neutron pick-up channels. For proton transfer channels the cross sections are roughly an order of magnitude less than the neutron transfer ones.

For Au-like ions, detected obviously with different magnetic fields, we got a very good $A/q$ resolution, shown in Fig. 2. The direct detection of Au-like ions was also an excellent opportunity to test for the first time the detector performance of PRISMA with large masses (actually with the highest beam mass presently available at LNL), a test important and necessary for future studies and developments. Work is underway to improve the tracking algorithm, necessary to properly extract the atomic charge state distributions of these very heavy ions.

THE KINETIC COINCIDENCE MEASUREMENT

During 2014, two major upgrades have been made around the target area of PRISMA, the installation of a new sliding seal scattering chamber and an additional time of flight system, to perform high resolution kinematic coincidences [12]. With the information provided by this second arm, we can associate the mass and nuclear charge distributions of heavy transfer products with each isotope identified in PRISMA.

The second arm [13] is composed of a Micro-Channel Plate (MCP) detector followed by a position sensitive Parallel Plate Avalanche Counter (PPAC) and an axial field ionization chamber also known as Bragg chamber (BC). The MCP is mounted in a transmission configuration at 10 cm from the target. The PPAC has an active area of 10x10 cm² (with two anode planes and a central cathode made of an aluminized mylar foil) and provides a timing signal for time of flight measurements (TOF) and X and Y position information (delay-line readout). The flight path (between MCP and PPAC) is $\sim$ 1 m. The BC has a 32 cm active depth and allows to perform the spectroscopy of the Bragg curve that provides energy $E$ (by integrating the area under the curve), the atomic number $Z$ (from the height of Bragg peak) and the Range (from the length of the Bragg curve).

Figure 3 shows a photograph of the new experimental set-up. One sees the beam line (from bottom), the sliding seal chamber (center), the PRISMA quadrupole magnet (right) and the second arm (left). In-beam tests of the new detector were performed before the final experiment using $^{32}$S and $^{58}$Ni beams at Tandem energies. The elastically scattered projectile ions from a Au target allowed to measure the energy resolution of the BC, which turned out to be about 1%. Analog electronics was used to process the signals from the BC, but preliminary tests have also been performed with digital electronics, with the output signal from the charge preamplifier of the BC sent to a V1724 CAEN Flash ADC.

In this improved configuration, a second experiment has been performed for the same $^{197}$Au+$^{130}$Te reaction at $E_{\text{lab}}$=1070 MeV, placing PRISMA and the second arm at the kinematically correlated angles of $\theta_{\text{lab}} = \pm 37^\circ$. Experimental conditions, i.e. beam current, target thickness etc., were very similar to the previous run. Data analysis is in progress. We expect to get important information on the production yield of heavy neutron rich partners and to measure the probability of transfer induced fission.

Fig. 3. Photograph of the PRISMA target area with the new sliding seal scattering chamber (center) and the second arm (left).