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Study of the multi-nucleon transfer reactions of ^{136}Xe + ^{198}Pt for producing exotic heavy nuclei

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Abstract. The feasibility of the multi-nucleon transfer (MNT) reaction in the ^{136}Xe + ^{198}Pt system was investigated for synthesizing neutron-rich heavy nuclei around mass number A~200 of astrophysical interest. Identification of the projectile-like fragments (PLF's) was successfully performed by using VAMOS++ spectrometer. The isotopic distributions of the PLF's produced by two-proton stripping and pickup reactions were compared with each other, demonstrating the properties of the MNT reactions observed in the present system. The two-proton pickup channels strongly populated than the two-proton stripping channels were observed. The isotopic distributions for different total kinetic energy loss (TKEL) ranges are also discussed. The overall enhancement of the strength of the two-proton pickup compared with the two-proton stripping appears to be related to the MNT reactions with relatively moderate energy dissipation.

1 Introduction

The neutron-rich isotopes around the mass number A~200 are astrophysically important since they lie at the last waiting point of the r-process towards the synthesis of uranium. But the current knowledge (e.g. half-life, mass, etc.) of such nuclides are only limited near the valley of stability. This is due to the difficulty of producing nuclei in such region using conventional radioactive nuclear production mechanism like fission or fragmentation. The multi-nucleon transfer (MNT) reaction recently attracts much attention as a good candidate to produce nuclides in this neutron-rich heavy mass region. In

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order to produce such exotic heavy isotopes using the MNT reaction, proton pickup and neutron stripping reactions are necessary. Most experiments performed with medium mass projectiles at energies around the Coulomb barriers favored neutron pickup and proton stripping channels. Even with the neutron-rich medium mass projectile (e.g. ^{64}Ni+^{238}U), the proton pickup channels were accessible, but the proton stripping channels were still dominant [1]. The heavy neutron-rich projectile such as ^{136}Xe which has a charge-to-mass ratio (Z/A) close to the target nucleus (e.g. ^{208}Pb or ^{198}Pt) is anticipated to give large cross sections for the MNT reactions producing neutron-rich target-like fragments (TLF's) [2–5]. However, the MNT reactions in such systems has not been well studied experimentally and theoretically. The recent experiments gave only partial information on the reaction products [6, 7]. For more detailed investigation of feasibility of the MNT reaction for producing neutron-rich exotic nuclei, we performed an experiment using ^{136}Xe+^{198}Pt system where the projectile-like fragment (PLF) and TLF were identified simultaneously on event-by-event basis. In this report, some preliminary results on the measured PLF of the two-proton transfer channels are presented.

2 Experimental Setup

The 91.6% isotopically enriched ^{198}Pt target was bombarded by the ^{136}Xe^{20+} ion beam from the CSS1 cyclotron at GANIL. The beam energy was 8 MeV/A, which is 60% above the Coulomb barrier, with the typical beam current of ∼0.3 pnA. The target thickness was 1.3 mg/cm^2. The large acceptance spectrometer VAMOS++ [8] was used for identification of the PLF. The spectrometer was set to 30° in laboratory frame close to the grazing angle of the PLF. An array of eleven Ge clover detectors EXOGAM [9] was used for the simultaneous identification of the TLF by measuring the de-excitation $\gamma-$rays. More details can be found in Ref. [10].

3 Results & Discussion

3.1 Particle Identification

The PLF was identified using information measured by the VAMOS++ spectrometer as described in Ref. [10]. The Resolution of the charge-state separation was $\Delta Q/Q{\sim}1/70$ (FWHM). The mass resolution was $\Delta M/M{\sim}1/200$ (FWHM). The resolution of the atomic number was $\Delta Z/Z{\sim}1/60$ (FWHM). These typical resolutions were of sufficient quality for the main purposes of the present investigation.

3.2 Isotopic distributions of two-proton stripping and pickup channels

In the present work, the detected yields were corrected by a typical acceptance value of 7% obtained by the simulation. The corrected yields were converted to the cross sections using a conversion factor obtained by matching the ^{136}Xe yield to the calculated Rutherford scattering cross section. We are now employed in a comprehensive study for the evaluation of the acceptance and the conversion factor. The PLF isotopic distributions corresponding to two-proton stripping (Te) and pickup channels (Ba) are shown by solid squares in Fig. 1. The vertical error bars includes the statistical errors and the systematic errors from the particle identification. The PLF distributions were further investigated for different total kinetic energy loss (TKEL) ranges, as shown in Fig. 2. The TKEL was calculated by using kinematical information of well identified PLF and assuming two-body kinematics for TLF. Although the present results are preliminary, we conclude tentatively as follows:

(1) The isotopic distribution of the two-proton pickup channels is relatively shifted to neutron-rich side; the centroid of the distribution is closer to the isotope corresponding to the pure proton

transfer channel (shown as a gray vertical bar in Fig. 1) than observed in the two-proton stripping channels. The distances are observed to be about two and seven neutrons for two-proton pickup and stripping channels, respectively. Such tendency seems to be observed in the results of the GRAZING calculation [11, 12] shown by histograms in Fig. 1. The two-proton pickup channels stronger than two-proton stripping channels are observed in the experiment, while the pickup channels are highly suppressed in the GRAZING calculation as compared to the stripping channels. The reason for such difference between calculation and measurement is not clear at the moment, and certainly further investigation is needed.

(2) The centroids of the isotopic distributions obtained for different ranges of TKEL are away from the isotope of pure proton transfer, with increasing TKEL values (see Fig. 2). Such behaviors are due to the secondary processes in the reaction; the higher the TKEL, the more neutrons are allowed to be evaporated from the PLF primarily produced by the MNT reactions in the first step of the binary collision.

(3) Especially, for the two-proton pickup channels, the cross sections corresponding to quasi-elastic collisions (i.e. for the events associated with TKEL between −25 and 75 MeV) are relatively larger than observed in the proton stripping channels. The overall enhancement in the strength of the two-proton pickup channels, stronger than the two-proton stripping as discussed above at (1), appears to be associated with the MNT reactions of relatively moderate energy dissipation.

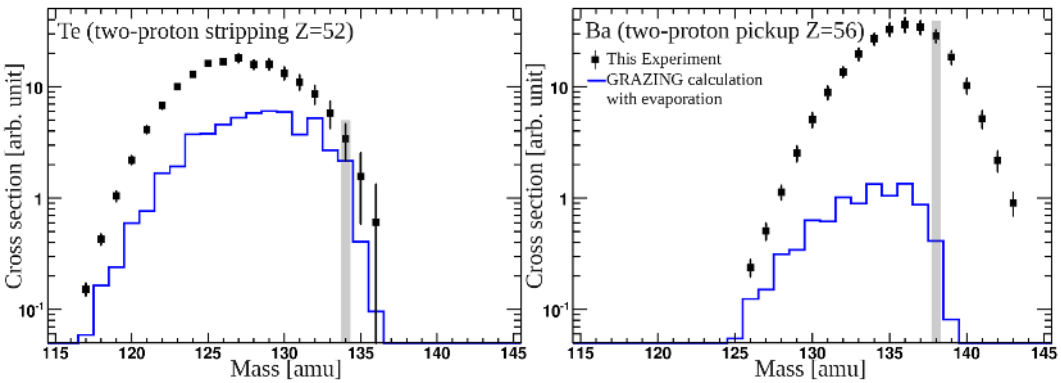

Figure 1. PLF isotopic distributions of two-proton stripping Te (Z = 52) channels (left), and the two-proton pickup Ba (Z = 56) channels (right). Solid squares indicate the measurements and histograms indicate the results of the GRAZING calculation [11, 12] with considering evaporation. The gray vertical bars indicate the pure proton transfer channels.

4 Summary

The experiment for measuring the MNT reaction cross sections of ^{136}Xe+^{198}Pt was successfully carried out. Preliminary cross sections of PLF's were deduced. Focusing on the two-proton stripping and pickup channels, the observed properties of the MNT reaction in this system were discussed. The stronger cross sections of the two-proton pickup channels relative to the two-proton stripping channels were observed, contrary to the GRAZING calculation. The centroid position of the isotopic

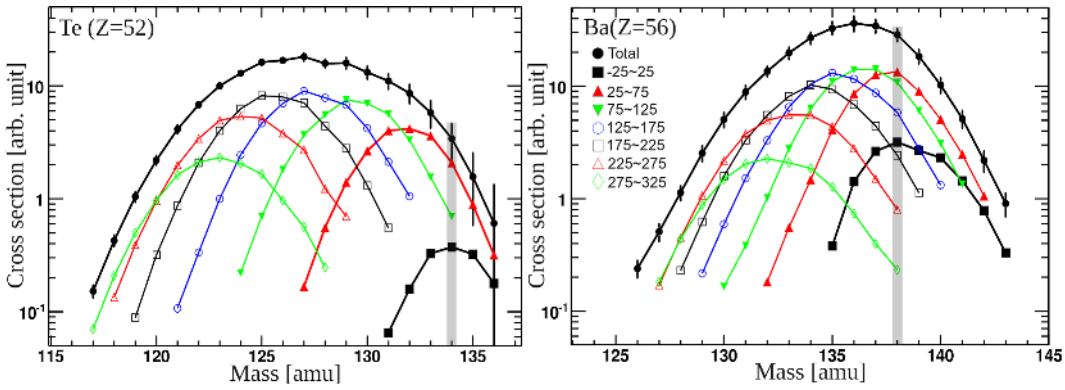

Figure 2. PLF isotopic distributions of two-proton stripping Te (Z = 52) channels (left), and the two-proton pickup Ba (Z = 56) channels (right) for different TKEL ranges. Total distributions are indicated by solid circles. Below the total distributions, isotopic distributions of every 50 MeV step in TKEL are presented. The lines are drawn to guide the eye. The gray vertical bars indicate the pure proton transfer channels.

distribution in the proton pickup channels was closer to the pure proton transfer channel than the proton stripping channels. The isotopic distributions produced by the GRAZING calculation, showed similar tendency of the measured centriod position. The overall enhancement of the cross sections in the two-proton pickup than the two-proton stripping, appears to be related with pronounced cross sections at the moderately dissipated energy region.

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