Evaporation residue cross-section measurements for ^{16,18}O+^{181}Ta reactions

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Introduction

Quasi-fission (QF), one of the hurdles in super-heavy element (SHE) production, had been predicted in heavy systems with the charge product, $Z_PZ_T > 1400$ [1]. However, the evaporation residue (ER) cross-sections measured for reactions forming ^{216}Ra compound nucleus (CN) are found to exhibit QF in very asymmetric combinations with $Z_PZ_T \approx 700$ [2]. Also, the presence of QF was reported in very asymmetric reactions forming ^{213}Fr, ^{210}Rn, ^{202}Po and ^{202}Pb nuclei [1, 3–6]. Thus a systematic understanding of the occurrence or start of QF, in light or heavy beams induced reactions with different target nuclei will be vital in SHE synthesis.

The dinuclear system passes through a long dynamical path, during which it equilibrates in all degree of freedom to form a CN. This CN which survives from fission, de-excites via γ emission or particle evaporation to form an ER. Thus the formation of ERs depends on capture cross-section (σ_{cap}), CN formation probability (P_{CN}) and its survival probability against fission (W_{sur}) through the relation, $\sigma_{ER} = \sigma_{cap} \times P_{CN} \times W_{sur}$. In heavy-ion collisions, the dinuclear system may re-separate before complete equilibration and thereby reduce P_{CN}. The corresponding ER cross-sections, at energies well above the fusion barrier is relatively insensitive to the form of the nuclear potential [5], and are mainly determined by Standard Statistical model (SSM) parameters [6]. Thus parameters like fission barrier scaling factor, k_f which relates to the fission barrier ($B_f(\ell)$) in agreement with the expression $B_f(\ell) = k_f * B_f^{LD}(\ell) + \Delta W_{gs}$ (Here $B_f^{LD}(\ell)$ the rotating liquid drop model fission barrier and ΔW_{gs} the ground state shell correction) and P_{CN} are used to explain the measured ER excitation function at higher energies. To Explore the onset of QF, two reactions ^{16,18}O+^{181}Ta forming ^{197,199}Tl CN is studied and reported here.

1. Experiment

The experiments are carried out at 15UD Pelletron accelerator facility at IUAC, New Delhi. A pulsed ^{16,18}O beams, with pulse separation 4 μs, were bombarded on an enriched ^{181}Ta target of thickness ≈ 170 μg/cm^2 with a carbon backing 20 μg/cm^2. ERs were separated from intense beam background using the Heavy Ion Reaction Analyzer (HIRA). HIRA was kept at 0° with respect to the beam direction with 10 msr entrance aperture. ERs were

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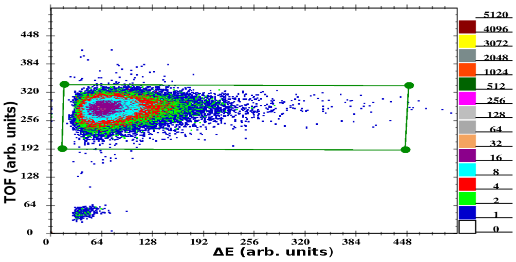

FIG. 1: ΔE vs TOF spectrum for ^{16}O+ ^{181}Ta at E$_{c.m.}$ = 86.15 MeV (94 MeV E$_{lab}$).

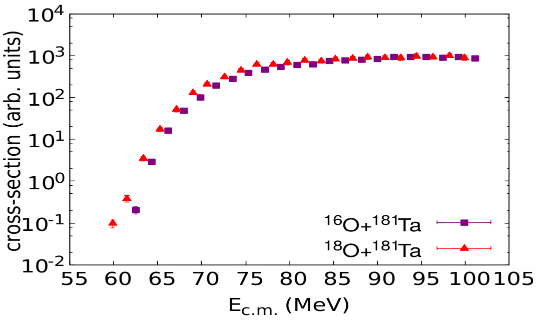

FIG. 2: Comparisons of ER excitation functions of ^{16,18}O+^{181}Ta reactions.

measured from 68–110 MeV beam energy in steps of 2 MeV. A Multi-Wire Proportional Counter (MWPC) of active area 150×50 mm^2 was placed at the focal plane (FP) of HIRA for the detection of the ERs. Two silicon surface barrier detectors of active area 50 mm^2 each with a collimator diameter 1 mm were placed at a distance of 95.6 mm from the target inside the target chamber at an angle of ±15° with respect to beam direction for normalization of ER cross-sections. A time of flight (TOF) was set up between anode of MWPC and RF signal to separate the beam-like particles from ERs. A two-dimensional spectrum between energy loss in MWPC and TOF is shown in Fig. 1

2. Data Analysis

The total ER cross-section was calculated using formula

$$\sigma_{ER} = \frac{Y_{ER}}{Y_{norm}} \left(\frac{d\sigma}{d\Omega}\right)_{Ruth} \Omega_{norm} \left(\frac{1}{\epsilon_{HIRA}}\right) \quad (1)$$

where Y_{ER} is the number of ERs detected at the FP of HIRA, Y_{norm} is the number of scattered beam particles detected by any of the monitor detectors, Ω_{norm} is the solid angle subtended by monitor detectors, $(\frac{d\sigma}{d\Omega})_{Ruth}$ is the differential Rutherford-scattering cross-section in the laboratory system, and ϵ_{HIRA} is the transmission efficiency of the HIRA. The transmission efficiency of HIRA was calculated, using a Monte Carlo code, TERS [8].

3. Results

The ER cross-sections for the reactions ^{16,18}O+^{181}Ta are compared in FIG. 2. Based on mass asymmetry α, and its critical value at Businaro-Gallone point (α_{BG}), one would have expected QF in ^{18}O+^{181}Ta ($\alpha < \alpha_{BG}$) reaction as compared to ^{16}O+^{181}Ta ($\alpha > \alpha_{BG}$). However, our analysis does not show any signatures of QF in ^{18}O+^{181}Ta. Hence, a detailed analysis using SSM code HIVAP[9] is in progress.

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References

[1] R. Rafiei et al., Phys. Rev. C **77**, 024606 (2008).
[2] A. C. Berriman et al., J. Nucl. Radiochem. Sci. **3**, 31 (2002).
[3] A. Shamlath et al., Phys. Rev. C 95, 034610 (2017).
[4] A. Shamlath et al., Nucl. Phys. A **945**, 67 (2016).
[5] L. Corradi et al., Phys. Rev. C **71**, 014609 (2005).
[6] R. N. Sagaidak et al., Phys. Rev. C **68**, 014603 (2003).
[7] A. K. Sinha et al., Nucl. Instrum. Methods Phys. Res. A **339**, 543 (1994).
[8] S. Nath, Comput. Phys. Commun. **180**, 2392 (2009); Comput. Phys. Commun. **181**, 1659 (2010).
[9] W. Reisdorf, Z. Phys. A. **300**, 227 (1981).