Measurement of ER cross-sections across $Z = 82$ shell closure

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Effects of proton or neutron shell closure on nuclear dynamics have been a topic of considerable interest. Existence of super heavy nuclei, beyond the macroscopic limit, depend solely upon microscopic stabilization through shell effects. Effects of proton and neutron shell closures, especially $Z = 82$ and $N = 126$, on fission fragment angular anisotropy [1, 2] and survival of evaporation residue (ER) against fission [3–6] have been studied. This work is aimed at investigating effects of $Z = 82$ shell closure in the compound nucleus (CN), if any, in enhancing ER survival against fission. We measured ER cross sections for three reactions leading to CN with same number of neutrons but different number of protons across $Z = 82$, *viz.* ${}^{199}_{81}\mathrm{Tl}_{118}$, ${}^{200}_{82}\mathrm{Pb}_{118}$ and ${}^{201}_{83}\mathrm{Bi}_{118}$.

The experiment was carried out at the 15UD Pelletron accelerator facility of IUAC, New Delhi. A pulsed ^{19}F beam, with pulse separation of 4 μs, was bombarded on ^{180}Hf (150 μg/cm^2), ^{181}Ta (170 μg/cm^2) and ^{182}W (100 μg/cm^2) targets with thin ($\sim$20 μg/cm^2) $^{\mathrm{nat}}$C backing. Measurements were performed at projectile energies (E_{lab}) in the range of 80–124 MeV. ERs were separated from the background events using the recoil mass spectrometer, Heavy Ion Reaction Analyzer (HIRA) [7]. Two monitor detectors were placed at laboratory angle (θ_{lab}) 15.5° with respect to beam direction, in the horizontal plane, for absolute normalization of ER cross sections (σ_{ER}). A thin (30 μg/cm^2) $^{\mathrm{nat}}$C foil was placed 10.0 cm downstream from the target to reset charge states of the ERs. A multiwire proportional counter (MWPC), having an active area of 15.0×5.0 cm^2, was used to record the ERs at the focal plane of HIRA. The HIRA was operated with 10 msr acceptance and at 0°. Time of flight (TOF) of the ERs were also recorded. Yields of ERs were extracted from the coincidence spectrum between energy loss ΔE (from the cathode of MWPC) and TOF.

ER excitation function for the reaction ^{19}F+^{181}Ta had been reported by Hinde *et al.* [8]. Nevertheless we measured σ_{ER} for this reaction, along with the same for the other two reactions, to ensure similar systematic errors, if any, in measured data. Transmission efficiency of HIRA (ϵ_{HIRA}) [9], essential for determination of absolute cross sections, was calculated using the semi-microscopic Monte Carlo code TERS [10] following the formalism described in Ref. [6]. Our results for ^{19}F+^{181}Ta matched the same reported in Ref. [8] within experimental uncertainties.

Capture cross sections (σ_{cap}, sum of ER and fission cross sections) for all the systems were calculated by the coupled-channels code CCFULL [11]. Experimental σ_{cap} for ^{19}F+^{181}Ta,

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as reported by Nasirov *et al.* [12], were reproduced by varying the potential parameters (V_0, r_0 and a) and including appropriate couplings in the calculation. Same potential parameters and similar coupling scheme were used for ^{19}F+^{180}Hf and ^{19}F+^{182}W to calculate capture cross sections as experimental $\sigma_{\rm cap}$ were not available for these two systems.

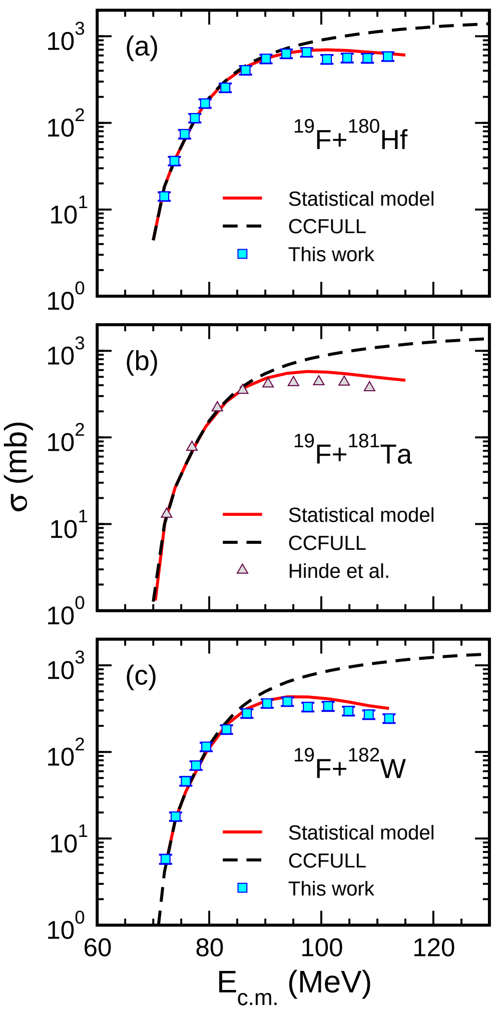

FIG. 1: Experimental and calculated $\sigma_{\rm ER}$ for (a) ^{19}F+^{180}Hf, (b) ^{19}F+^{181}Ta and (c) ^{19}F+^{182}W. Theoretical capture cross sections, calculated by CCFULL, are also shown for each system.

Statistical model calculations were performed for all the three system using the code VECSTAT [13]. Partial capture cross sections (σ_ℓ), generated by CCFULL was used as the input of the statistical model. We followed the transition-state model of Bohr and Wheeler for fission and used the finite range liquid drop model (FRLDM) fission barrier. Shell effect in the level density parameter and shell correction in fission barrier were included in the calculation. Experimental nuclear masses were used to calculate particle separation energies.

Fig. 1 shows the experimental ER excitation functions along with VECSTAT predictions for the three reactions. Experimental $\sigma_{\rm ER}$ appear to be lower than model prediction at higher values of $E_{\rm lab}$ in all three cases. It is not easy, though, to make definitive conclusions about effects of $Z = 82$ shell closure from these plots. Mismatch between measured and calculated $\sigma_{\rm ER}$ may also be caused by the presence of non-compound nuclear fission (NCNF) [14] or long-lived isomeric states in the populated ERs, as was reported in Ref. [6]. Further work to quantify probable effects of these two phenomena is essential.

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