The predicted production cross sections using HIVAP code for the synthesis of unknown isotopes of element Fm

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Introduction

Super heavy element (SHE) research has reached a high degree of sophistication and elements up to Z=118 have been produced. However a gap remains in the upper end of the nuclear chart between the isotopes produced in cold- and hot-fusion reactions. It is a challenging task to synthesise the missing isotopes experimentally for which suitable projectile target combinations may not be available. Theoretical energy dependent evaporation residue cross-section (σ_{ER}) calculations are useful in assisting experimentalists to plan future experiments. As an illustration we present the calculated production cross-sections using the HIVAP [1] code to synthesise presently unknown Fermium isotopes.

Details of the calculations

The HIVAP code is based on the conventional fusion-fission dynamics and therefore calculations involve two steps: complete fusion and the subsequent statistical de-excitation of the compound nucleus producing the evaporation residue (EVR) of interest. The HIVAP code requires several input parameters. Our aim here is to derive a single parameter set which can be used over a wide range of reactions required to synthesise SHE. As a first step we carried out sensitivity tests and studied the dependence of the production cross-sections to individual parameters by varying them separately. We find that the calculations are sensitive only to a small subset of parameters and therefore, the rest of the parameters can be "frozen". New values for this subset of parameters are proposed [2], which differ from that initially, used by Reisdorf [1], are listed below along with the originally used values by Reisdorf [1] (given in parenthesis).

1. Scale parameter for the level density LEVELPAR = 1.16 (1.153)
2. Level density ratio $a_f / a_n = 2$ (1)
3. Initial value of the nuclear potential (Mev) V0 = 50 (70)
4. Radius parameter (fm) R0 = 1.10 (1.12)
5. Diffuseness parameter (fm) D = 0.5 (0.75)
6. Quadrupole moment of target nucleus (fm^2) Q2 = 0 (1050)
7. Fluctuation of interaction barrier (% R0) SIGR0 = 2.5 (3).

This single parameter set describes all available hot fusion reactions with ^{48}Ca projectile incident on actinide targets reasonably well. An additional scaling based on the mass asymmetry $\eta = (M_T-M_P)/(M_T+M_P)$, where M_T and M_P are masses of target and projectile, respectively, is used for reactions involving lighter projectiles (e.g. O, Ne, and Si) on actinide targets. In addition, it is found that 3 parameters (BARFAC, V0 and D) need to be scaled by a factor X=1.3. The factor $X = \eta/\eta_{ref}$, where η_{ref}=0.669, which corresponds to the mass asymmetry value for the reference reaction ^{48}Ca+^{242}Pu.

Results and discussion

Calculated excitation functions for the reactions ^{16,18,20,22}O+^{238}U leading to the synthesis of various isotopes of Fermium are displayed in Fig. 1. Available experimental data for the 4n, 5n and 6n are included in the plot for the reaction ^{16}O+^{238}U. The incident beam energy varies from 3.545 to 7.500 MeV/nucleon.

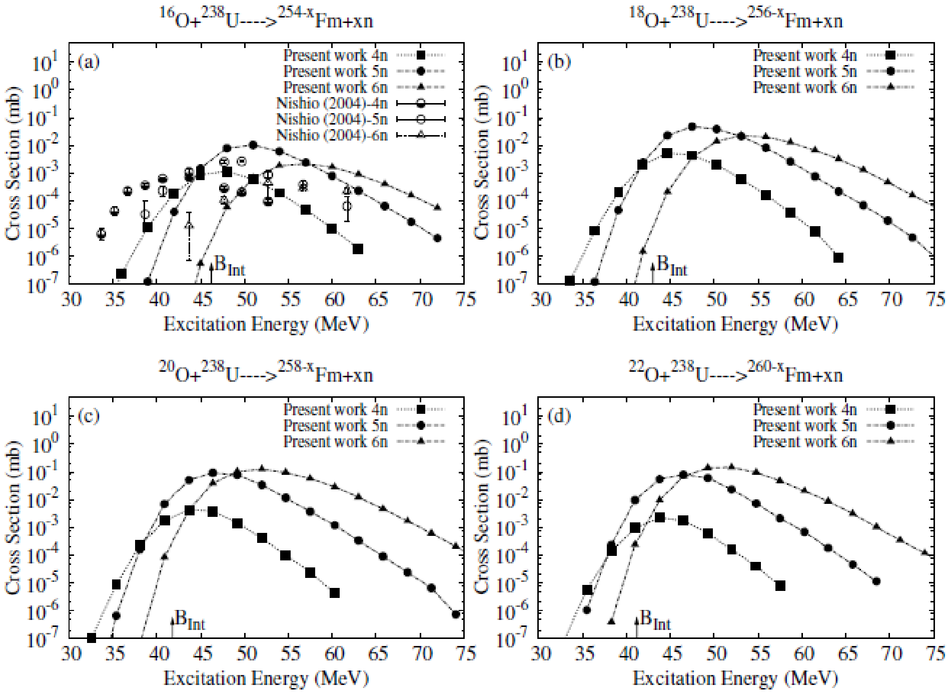

Fig.1: Excitation energy (E*) dependence of the evaporation residue cross-sections for the reactions $^{16,18,20,22}O+^{238}U$ leading to the synthesis of various isotopes of the element Fermium. Available experimental data for sub-barrier fusion [3] for 4n (half-filled circles), 5n (open circles) and 6n (open triangle) evaporation channels are included in the plot for the reaction $^{16}O+^{238}U$. The dotted line with solid squares, solid circles and solid triangles represents the present work HIVAP calculations for the 4n, 5n and 6n channels, respectively. The arrow corresponds to the Bass interaction barrier (B_{int}= Bass barrier + Q).

It is observed that for all the projectiles used, the position of the maximum cross-sections remain almost unaltered for the isotopes in the 4n, 5n and even the 6n evaporation channels with calculated cross sections on the order of micro-barns. The magnitude of the production cross-section increases with projectile mass. The maximum cross-section is reached for the 5n channel in the case of ^{16}O (10 μb) and ^{18}O (93 μb) projectiles. The maximum cross-section for the 6n channel with ^{20}O (≈140 μb) and ^{22}O (≈140 μb) projectiles is also included for completeness though experimental measurements for this will be difficult. The experiments can be performed at the available facilities if these and other neutron rich oxygen isotopes are produced in sufficient quantities (>10^8 ions), possibly with RIB beams in the foreseeable future. They can be considered as viable experiments for the synthesis of new and heavier isotopes of the element Fermium.

Acknowledgements:
This work is performed in partial fulfilment of the PhD degree at MCNS, Manipal University by H. M. Devaraja.

References

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