Establishing the Island of stability for superheavy elements: A new approach based on reaction data

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Introduction

A fascinating challenge in the study of superheavy nuclei is the quest for island of stability where the magic numbers next to Z=82 and N=126 may be located. The earliest calculation of 1960's established that the center of island of stability for superheavy elements (SHEs) lies at Z=114, N=184. Recently, the microscopic mean field models, applied in the region of SHEs, predict Z=120 and N=172 or 184 as the next magic numbers [1, 2]. Also, Z=126, N=184 have been used/predicted as magic numbers [3]. The goal of present work is to identify which one of these three Z (=114, 120 or 126) is a better shell closure with N=184. To this end we use the hot fusion reaction ^{48}Ca+^{238}U→$^{286}112^*$, with measured evaporation residue (ER), fusion-fission (ff) and quasi-fission (qf) cross-sections, as a tool and analyse it on the basis of the dynamical cluster-decay model (DCM) of Gupta and collaborators (see, e.g., [4] and earlier references therein) where the effects of deformation up to hexadecapole deformation β_4 and "compact" orientations θ_c (θ_c=72^0 for ^{238}U) are included. The DCM gives a good description of the ER (the light-particle emission), ff and qf (equivalently, capture) decay channels, and their excitation functions within a single parameter description, the neck length parameter ΔR.

The Methodology

The compound nucleus (CN) decay cross-section in DCM, in terms of partial waves, is

$$\sigma = \frac{\pi}{k^2}\sum_{\ell=\ell_{min}}^{\ell_{max}}(2\ell+1)P_0P;\ k=\sqrt{\frac{2\mu E_{cm}}{\hbar^2}} \quad (1)$$

with reduced mass μ=[A$_1$A$_2$/(A$_1$+A$_2$)]m, and center of mass energy E_{cm}. P is the WKB penetrability, with first turning point $R_a = R_1(\alpha_1,T)+R_2(\alpha_2,T)+\Delta R(T)$. P_0 is the solution of stationary Schrödinger equation in mass asymmetry coordinate η =(A$_1$-A$_2$)/(A$_1$+A$_2$), i.e., $P_0(A_i) \propto|\psi(\eta(A_i))|^2$, i=1,2, with mass fragmentation potential

$$\begin{aligned} V_R(\eta,T) &= \sum_{i=1}^{2}\Big[V_{LDM}(A_i,Z_i,T)\Big] \\ &+\sum_{i=1}^{2}\Big[\delta U_i\Big]exp(-\frac{T^2}{{T_0}^2}) \\ &+E_c(T)+V_P(T)+V_\ell(T). \quad (2) \end{aligned}$$

Here, $V_{LDM}(T)$ is T-dependent liquid drop energy [5], with its constants at T=0 re-fitted to give the experimental binding energies B, defined within the Strutinsky renormalization procedure as $B = V_{LDM}(T=0)+\delta U$, with the shell corrections δU calculated in the "empirical method" of Myers and Swiatecki [3]. The magic numbers for superheavy region in the "empirical method" [3] are taken as Z=126, N=184. Evidently, the constants of $V_{LDM}(T=0)$ need to be refitted to give the experimental B, for the magicity at Z=126 changed to that at Z=120 or 114, respectively. Then, P and P_0 are obtained for the three sets of magic numbers, and cross-sections calculated for the three decay processes of ER, ff and qf. Then, the excitation functions are fitted within a single parameter ΔR.

Calculations and Results

First of all, in Fig. 1, only the evaporation residue σ_{ER} is fitted for any one set of magic numbers and, using the parameter ΔR so obtained, the corresponding σ_{ER}'s are calculated for other two sets of magic numbers. Clearly, the σ_{ER} always remains the largest for magic set Z=126, N=184, independent of E^*, and the lowest for Z=114, N=184. However, in Fig. 2, when the fitting procedure is carried out simultaneously for all the three processes

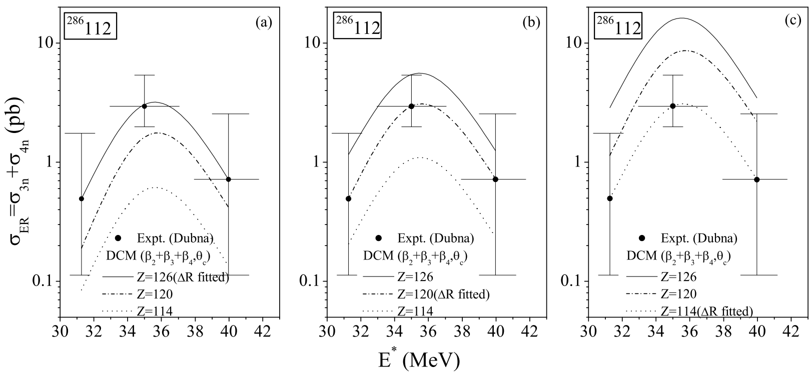

FIG. 1: ER as a function of CN E^* for ^{48}Ca+^{238}U$\rightarrow^{286}$112* reaction, calculated for the parameter of DCM fitted to data, respectively, for Z=126, 120 or 114, N=184 in the panels (a),(b) and (c).

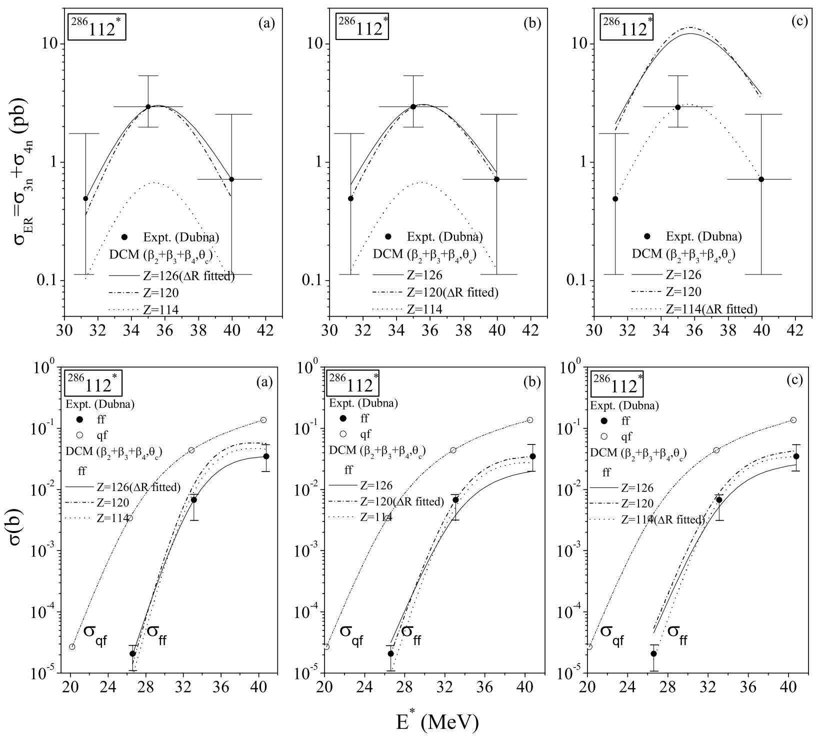

FIG. 2: Same as for Fig. 1, but now for ER, ff and qf. The qf is independent of magic shells.

of ER, ff and qf, the cross-sections are the largest and nearly indistinguishable for Z=120 and 126, N=184. This preliminary result suggests that Z=120 or 126 with N=184 are the equally strong magic shells (largest shell corrections), and Z=114, N=184 are the weakest magic shells.

References

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