Investigation of the reaction partners for the formation of super heavy elements and different decay modes

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Introduction

One of the fundamental quests which drive the nuclear physics studies is the exploration of limits of existence of the periodic table, search of novel magic numbers and reaching the stability peninsula. During last two decades, significant experimental ventures were undertaken to synthesize the elements in super heavy mass region [1-3]. To plan the experiments for the synthesis of super heavy elements (SHE), substantial theoretical support is indispensable to probe the suitable project-target combinations, projectile energy, estimation of fusion and survival probability of SHE. The quantum mechanical fragmentation theory (QMFT) [4,5] proved to be a powerful theoretical tool to predict the cold fusion valleys, which led to achieve the dreams of SHE formation.

In the present work, we look for the probable projectile-target combinations for the synthesis of even-Z SHE having $104 \leq Z \leq 118$, within QMFT. Also, we analyze the role of deformations and relative orientation of deformed nuclei namely cold/non-compact optimum orientations and hot/compact optimum orientations upon the potential energy surface (PES) of SHE. For the spherical case, the PES indicates the symmetric mass fragmentation but for deformed case it depicts the asymmetric mass distribution. The change in PES for intermediate mass fragments, heavy mass fragments and fission fragments is noted for hot and cold optimum orientations, comparatively. We also identify some probable projectile-target combinations, in addition to experimentally employed reaction partners, for the synthesis of even-Z SHE with Z = 104-118, which can be explored in future experiments.

Methodology:

The QMFT [4] is a unified theory of fusion reaction and other related processes of fission and cluster radioactivity that was predicted prior to their experimental observations. The QMFT is worked out in terms of the following collective coordinates:

(i) Relative separation coordinate R between the two nuclei

(ii) Mass and charge fragmentation co-ordinates, defined by the mass and charge-asymmetry coordinates as

$$\eta = (A_1 - A_2)/A, \quad \eta_Z = (Z_1 - Z_2)/Z$$

Here $A = A_1 + A_2$, and $Z = Z_1 + Z_2$. A_i, Z_i ($i = 1; 2$) are, respectively, the mass number and charge number of two fragments. The limiting values of η are $0 \leq \eta \leq 1$, and thus allows a unified description of a few-nucleon or multi-nucleon (a cluster) transfer, a large-mass transfer, the complete fusion (η = 1) of nuclei and the symmetric (η = 0), asymmetric and super-asymmetric fission of a nucleus or compound nucleus. The Z coordinate gives the associated charge distribution effects.

(iii) The deformation co-ordinates $\beta_{\lambda i}$ (λ=2,3,4... and i=1,2) of the colliding nuclei or fragments.

(iv) The orientation degrees of freedom θ_i (i=1,2) of the deformed nuclei.

(v) Azimuthal angle ϕ between the principal planes of the two colliding nuclei.

The fragmentation potential is defined as the resultant of binding energies of the interacting nuclei with shell corrections duly included, the long range Coulomb potential (V_C), and the

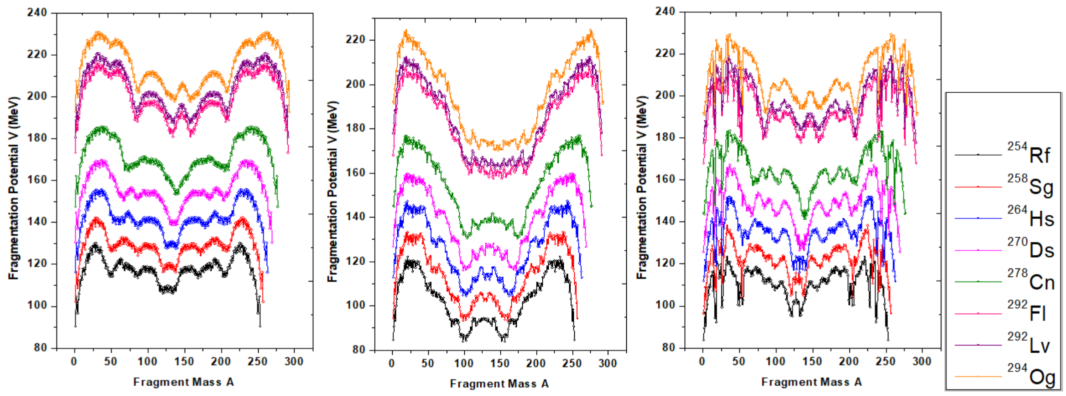

Figure 1: *Mass-dependence of fragmentation potential for SHE Z=104-118 with even Z-values for (a) spherical case (b) cold fusion case (c) hot fusion case, respectively (from left to right).*

attractive proximity potential (V_P) coming into picture as the two interacting nuclei lie in immediate vicinity of each other, given as

$$V(\eta)=\Sigma B_i(A_i,Z_i,\beta_{\lambda i})+V_c(R,Z_i,\beta_{\lambda i},\theta_i)+V_P(R,A_i,\beta_{\lambda i},\theta_i)$$

Calculations and Discussions:

Fig.1 presents the comparative fragmentation potential plot of Z =104-118 SHE with even-Z values for spherical, cold and hot fusion cases. For spherical case, the neutron evaporation and α-emission are seen to be the dominant decay paths together with some probability of spontaneous fission ($A_{CN}/2 \pm 30$). With inclusion of quadrupole deformations, the potential energy surface (PES) is approximately alike for light particles (LPs), intermediate mass fragments (IMFs) while a significant difference ascends in the fragmentation behavior for heavy mass fragments (HMFs) and fission region. The symmetric mass fragmentation is seen for spherical case which changes to asymmetric one by inculcation of cold non-compact optimum orientations (Figs. 1 (a, b)). In the disintegration path, it is noted that the spontaneous fission strongly competes with neutron emission channel for non-compact cold fusion case. Further, the strong variations arise in the structure of PES for compact hot orientations, which withstand smooth for spherical nuclei case. The structure of symmetric mass distribution is altered for hot fusion case compared to spherical case.

From Fig. 1 we note that the fragmentation potential magnitude is least for ^{254}Rf and upsurges with increasing atomic number of super heavy nuclei. It advocates that ^{254}Rf is less prone to decay as compared to heavier super heavy nuclei. There are several minima's in the PES but the deep minima lie across Pb and its complementary fragment. For cold fusion case, asymmetric mass distribution is predominant, while for Z = 114, 116, 118 it changes to symmetric. However, for hot fusion case, the symmetric mass distribution in the fission region is preferred for Z = 104-112 with even-Z. On the other hand, for heavier super heavy nuclei Z = 114, 116, 118 the asymmetric mass distribution comes into picture. The suitable projectile-target combinations are noted corresponding to the minima in the PES for spherical case, cold and hot optimum orientations case, in addition to the experimentally employed reaction partners. The details can be found in the elaborative study presented in ref. [6].

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