Decay of Superheavy Nuclei Formed in Collisions of Deformed and oriented Nuclei

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Introduction

The search for super-heavy elements ($Z > 100$) explores the borderline of the nuclear chart towards its upper end where the strong Coulomb force acting between the many protons dominates the nuclear stability and finally terminates the number of elements by instability against fission. The SHEs allow nuclear physicists to explore concepts such as “magic numbers” and the “island of stability”, which help us understand why some nuclei are more stable than others. They can also be used to test the predictions of different models of the nucleus and, ultimately, they may help us to understand why nature contains only a finite number of elements. The lifetimes of the heaviest elements were found to be very short. But this instability of SHEs does not seem to be inevitable. The island of stability describes the possibility of elements with particularly stable “magic numbers” of protons and neutrons. There is no consensus among theorists with regard to the center of the shell-stability in the superheavy region.

Since the pioneering work of late 1960’s of Lund Group, using one center oscillator, and that of Frankfurt School, using two center shell model, it is established that the center of island of stability for SHEs (the next magic numbers beyond Z=82, N=126) lies at Z=114, N=184. Furthermore, the recent Dubna data on Q_α-values for $^{291}116$ and $^{294}118$ decay chains do *not* show any (shell) structure effects of the Z=114 magicity . On the other hand, there is *no* available shell model that predicts Z=120 as the next magic charge number. In this thesis, by studying the excitation functions of superheavy nuclei, we have tried to explore the yet unknown nuclear landscapes and to establish the “island of stability”. The role of static deformation and compact orientation of target nucleus in measured fusion-evaporation residue, fusion-fission and capture cross-sections of superheavy nuclei has been studied.

Results and Discussions

The basis of our work is Dynamical Cluster decay Model(DCM), which is based on Quantum Mechanical Fragmentation Theory. In DCM, the emission of neutrons constituting the evaporation residue and other heavier frgaments like in fusion-fission are treated as the barrier penetration of preformed clusters at the point of closest approach, thereby including the dynamical and nuclear structure effects explicitly. For the competing quasi-fission, the DCM considers only the incoming channel with a preformation factor of unity.

As a first application, the DCM with effects of deformations of the incoming nuclei or of outgoing fragments and their “compact” orientation degrees of freedom included, is used to calculate the fusion-evaporation residue, fusion-fission and quasi-fission excitation functions of an “equatorial” compact (θ_c=90^0 for ^{244}Pu) hot fusion reaction ^{244}Pu+^{48}Ca ([1]-[3]). The quasi-fission is also calculated for the “polar” elongated (θ_c=0^0 for ^{244}Pu) configuration of cold process. Using the higher multipole deformations upto hexadecapole, i.e., $\beta_2 + \beta_3 + \beta_4$, we find that, with in one parameter fitting, the DCM gives a very good description of the excitation functions for light-particle (here xn, x=3-5) decay channels, the fusion-fission and the quasi-fission of ^{244}Pu+^{48}Ca reaction forming the compound nucleus $^{292}114^*$ of super-heavy element Z=114. The single fitting parameter used is the neck length $\Delta R(T)$, which is the largest for evaporation residue due to the (prompt) emission of neutrons, smaller for the competing quasi-fission and finally the smallest (forming a necked configuration) for fusion-fission of hot compound nucleus. A sensitivity check of the calculations shows that the fusion excitation functions calculated for such hot fusion reactions at their respective compact orientations for cases of $\beta_2+\beta_3+\beta_4$ or of quadrupole deformation β_2 alone, are shown to be much larger than for the case of all the nuclei taken to be spherical, signifying that the increase in fusion threshold for an intermediate hot fusion reaction is associated with the static deformation of the target nucleus and its compact orientation at the point of collision in its path toward the (spherical) compound nucleus.

Next, we study the effect of using different magic numbers for the superheavy region on fusion-evaporation residue cross sections, taking ^{48}Ca+^{238}U→^{286}112* as an example [4]. In other words, for seeing what differences would arise as a result of the proton magic shell being at Z=120 or 126, instead of the commonly used Z=114, with N=184, we have calculated the fusion-evaporation residue cross sections σ_{ER} for all the three cases of Z=114, 120 or 126 and N=184 as magic numbers. Note that the chosen ^{48}Ca+^{238}U reaction forms a non-equatorial compact (θ_c=72^0 for ^{238}U) hot fusion configuration. The shell corrections are calculated by using the "empirical" formula of Myers and Swiatecki for Z=126, 120 or 114 with N=184 as the closed shells, and the constants of liquid drop energy due to Davidson *et al.* adjusted in each case to obtain the experimental binding energies. Our calculations using fusion-evaporation cross-sections alone seem to demonstrate that Z=126, N=184 are the strongest magic numbers (largest shell corrections), and that Z=114, N=184 as the weakest (smallest shell corrections), since the fusion evaporation cross sections for use of Z=126, N=184 remain the largest, and that due to Z=114, N=184 as the lowest, with Z=120, N=184 presenting as the second best result, independent of the compound nucleus excitation energy E^*.

However, it is relevant to remind here that ^{48}Ca+^{238}U→^{286}112* reaction also show other decay products of fusion-fission and quasi-fission processes, and hence it will be interesting to see next if the above result remains the same when all the three phenomena are included in the analysis. Therefore, we consider the total data on three cross-sections (σ_{ER}, σ_{ff} and σ_{qf}) simultaneously for a best fit of the only parameter of the model, the neck-length $\Delta R(E^*)$[5]. We consider all the four cases of magic numbers Z=114, 120 or 126 with N=184 and Z=120, N=172 for obtaining the shell corrections from the "empirical" formula of Myers and Swiatecki. Our calculations clearly demonstrate that when the fitting procedure is carried out simultaneously for all the three processes of evaporation residue, fusion-fission and quasi-fission processes, (quasi-fission is independent of magic shells), the evaporation residue cross-sections are the largest for Z=126 or Z=120, N=184, but then, independent of E*, the fusion-fission cross-sections are always the highest for Z=120, N=184, the cross-sections for Z=114, N=184 and Z=120, N=172 always remaining lower. This result suggests that Z=120 and N=184 are the strongest magic numbers (largest shell corrections) and might form center of island of stability.

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