Dynamics of nuclear reactions in superheavy mass region

Kirandeep Sandhu*
School of Physics and Materials Science,
Thapar University, Patiala - 147004, Punjab, INDIA

Introduction

The understanding of island of stability beyond Z=82 and N=126, is one of the most sorted aspect in present context. For this, enormous experimental and theoretical work have been made in different scientific centers around the globe. To locate the land of the superheavy elements, the successful application of macroscopic-microscopic, relativistic and non-relativistic mean field theories suggested that the superheavy magic proton shell should exist at Z=114 or 120 or 126 with the neutron magic number predicted at N =172 or 184. The experimental efforts to approach the superheavy mass region are undertaken by the well known cold and hot fusion processes followed by various decay channels such as neutron evaporation, fusion-fission and quasi-fission. The α-decay and spontaneous fission are also assigned as the main disintegration channels of heavy and superheavy nuclei, which usually occur from the residual nucleus formed subsequent to the neutron evaporation process. In addition to this, theoretical analysis of heavy particle radioactivity (HPR) with Z >110 is also an ongoing quest for the decay of superheavy nuclei.

In view the above discussion, the present work contains the analysis of various decay modes from a number of superheavy compound nuclei, ranging Z=104-117, using Dynamical Cluster Decay Model (DCM)[1], which is the reformulation of the Preformed Cluster Model (PCM) [2]. The difference in DCM and PCM lies in the fact that temperature and angular momentum effects are duly incorporated in former framework whereas such effects remain silent in the later methodology. Hence excited state decay processes such as fusion-fission, quasi-fission and neutron evaporation are addressed via DCM framework, whereas α-decay and HPR are studied in PCM formalism.

Calculations and Results

First, in order to address the role of shell effects for the superheavy mass region, the decay analysis of $^{296}116^*$ and $^{266}\mathrm{Rf}^*$ compound systems is carried out in the DCM framework, using sticking (I_S) and non-sticking (I_{NS}) approaches of the moment of inertia. The comparative behavior of fragmentation potential, preformation probability and cross-sections for xn- channels of these nuclei show that Z=126 and N=184 is the best superheavy magic pair for understanding the neutron evaporation residues in DCM. On the other hand, Z=120 and N=184 shell closures are taken to address the fusion-fission process nicely. Following this, the application of Z=126 and N=184 shell closures is tested for the variety of the superheavy nuclear systems such as $^{297}117^*$, $^{291}115^*$ and $^{290,292}114^*$ nuclei using β_{2i}-deformations and hot optimum orientations.

In the neutron evaporation of $^{297}117^*$ superheavy nucleus, the measured data could not be fitted by using spherical fragmentation approach. However, with the inclusion in the deformation effects upto β_{2i}, the available data for $2n$ and $3n$ decay cross-sections could be addressed quite nicely but the $4n$-decay cross-sections are underestimated by about 25%, which indicated the possibility of some other competing evaporation residue, like the ^{4}He decay, contributing to $4n$-decay cross-sections. Hence the importance of the role of deformations is justified from the decay analysis of $^{297}117^*$ nucleus. To explore this result further, the dynamics of $^{48}\mathrm{Ca} + {}^{243}\mathrm{Am}\rightarrow{}^{291}115^*$

*Electronic address: `Kiransndh250@gmail.com`

reaction is also investigated in the framework of DCM. Here also, $3n$ and $4n$-decay cross-sections are addressed nicely with the inclusion of the deformation effects, where as $2n$-decay corresponds to spherical and deformed fragmentation approaches both. The potential energy surfaces (PES) for the spherical approach shows symmetric fission fragmentation, whereas asymmetric peaks in heavy fragment mass region are observed for the deformed choice. However, the potential energy surfaces (PES) are almost identical for static and dynamic choices of deformations.

In addition to the neutron evaporation, the ground state decays such as α-emission and heavy particle radioactivity (HPR) are also discussed in the present work. The α-decay chains from ^{287}115, ^{288}115 and ^{289}115 nuclei are investigated by using the Preformed Cluster Model (PCM) for spherical and deformed fragmentation approaches. A nice fitting of the experimentally observed half-lives is obtained with in a constant scaling factor in penetration probability, using"hot" optimum orientations, rather than the usual "cold" ones. Using the same orientation approach i.e. "hot" optimum orientations, an attempt is made to examine the possibility of heavy cluster emission from ^{278}113, $^{287-289}$115 and ^{293,294}117 isotopes resulting in a doubly magic ^{208}Pb daughter or its neighboring nuclei. The calculations are performed within the framework of PCM using Prox-77 and Prox-00 interaction potentials. The decay structure remains almost identical for both proximity potentials with spherical as well as deformed fragmentation approaches.

Besides the deformation effects, the explicit role of orientations is also addressed by studying the dynamics of ^{268}Sg* nucleus formed in the ^{30}Si+^{238}U reaction, using optimum orientations. In DCM, the optimum orientations are fixed for cold polar (elongated) and hot equatorial (compact) configurations [3], respectively, for the configurations corresponding to largest interaction radius with lowest barrier and smallest interaction radius with highest barrier. The calculations at above barrier energies are performed by considering the hot equatorial configuration, for which symmetric distribution of fragments can be seen. On the other hand, asymmetric fragmentation is observed at below/or sub barrier energies for cold polar configuration. Symmetric mass distribution corresponds to the fusion-fission process whereas quasi-fission is characterized by asymmetric mass fragmentation. The same results are obtained for the decay analysis of ^{278,286}112* nuclei, using β_{2i}-deformations and optimum orientation approach. On the other hand, with the inclusion of the β_{4i}-deformations, the degree of compactness changes as θ_c=72^0, which is otherwise $\sim 90^0$ for ^{40,48}Ca+^{238}U$\rightarrow$^{278,286}112* reaction using β_{2i}-deformations. The comparative decay analysis of ^{278,286}112* nuclei clearly reveals the fact that contribution of quasi-fission is higher for the neutron deficient nucleus of Z=112. Finally isospin effects are studied for Z=114 and 115 superheavy isotopes. In the decay of ^{288,290,292,294}114* nuclei, the isotopic dependence is analyzed via the distribution of the preformation probability and fragmentation potential of the decaying fragments. Some slight variations in heavy mass fragment (HMF) and fission region are observed, but in general the trend is similar. The role of isospin is also studied for Z=115 isotopes formed in ^{48}Ca+^{241}Am, ^{48}Ca+^{243}Am and ^{48}Ca+^{245}Am reactions and $2n$, $3n$ and $4n$ cross-sections are predicted for ^{289}115* and ^{293}115* compound nuclei.

Acknowledgments

I am thankful to Prof. Manoj K. Sharma and Prof. Raj K. Gupta for their guidance and support, and DST for financial help.

References

[1] K. Sandhu, M. K. Sharma, R. K. Gupta, Phys. Rev. C **85**, 024604 (2012).
[2] G. Sawhney, K. Sandhu, M. K. Sharma, and R. K. Gupta, Eur. Phys. J. A **50**, 175 (2014).
[3] R. K. Gupta, M. Balasubramaniam, R. Kumar, N. Singh, M. Manhas, and W. Greiner, J. Phys. G: Nucl. Part. Phys. **31**, 631 (2005).