Comparative study of α and cluster radioactivity with and without shell corrections

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Introduction

An alpha particle emission is type of spontaneous decay in which radioactive nucleus emits a cluster of two protons and two neutrons i.e. a helium nucleus. A cluster emitted heavier than α particle i.e. having mass A$\geq$ 4 but lesser than the fission fragments is known as Cluster Radioactivity (CR). The interesting thing about these decays is that it occurs in nuclei to achieve stability by reducing size of the nucleus. The radioactive nuclear decay studies have contributed immensely to our understanding of the related nuclear structure aspects and associated properties. The selected cluster radioactive decays have been investigated within the the collective clusterisation approach of quantum mechanical fragmentation theory (QMFT) [1] based preformed cluster decay model (PCM), specifically, which lead to ^{208}Pb daughter nucleus always through emission of clusters i.e. ^{14}C-^{34}Si [2].

Recently, the importance of shell corrections, δU within QMFT have been explored in the process of CR. The results quantitatively established that the δU along with V_{LDM} plays a crucial role to give proper understanding of CR [3]. This work further motivates us to study the role of shell corrections on α radioactivity alongwith CR. In the present work, we have studied the comparative decay of α and cluster radioactive decay of parent nuclei in trans-lead region. It is pointed out here that CR cases chosen here have always doubly magic ^{208}Pb daughter nucleus i.e. having Z = 82 and N = 126. It is relevant to mention here that within PCM, α and cluster nuclei are assumed to be preborn with certain preformation probability i.e. ${P_0}^{\alpha}$ and ${P_0}^{C}$, respectively, before penetrating the respective potential barriers. It will be interesting to investigate the relative preformation probabilities i.e. ${P_0}^{C}/{P_0}^{\alpha}$, with and without inclusion of shell corrections, within the QMFT.

Methodology

The decay constant in the PCM [2] is defined as,

$$\lambda = \nu_0 P P_0. \tag{1}$$

Here ν_0 is the impinging frequency with which the cluster hits the barrier and P_0 is the preformation probability at a fixed R on the decay path.

$$P_0(A_2) \propto |\psi^{\nu}(A_2)|^2 \tag{2}$$

The structure information of the parent nucleus enters through the P_0 which inturn depends on the fragmentation potential $V_R(\eta)$, calculated as

$$V_R(\eta) = \sum_{i=1}^{2}[V_{LDM}(A_i, Z_i)] + \sum_{i=1}^{2}[\delta U_i] + V_C(R, Z_i) + V_P(R, A_i) \tag{3}$$

Here V_{LDM} and δU are, respectively, the liquid drop and shell correction [4] energies.

The work during last decade has separated the contributions of liquid drop energy V_{LDM} (T = 0) and shell corrections δU (T = 0) in the binding energy [5]. In the present work, we look for the role of δU in the ground state decay of radioactive parent nuclei.

Calculations and discussions

The fragmentation potential is calculated for the ground state decay of parent nucleus ^{238}Pu, for spherical consideration of the fragment nuclei, as shown in Fig.1 (a). We observed here that there is emission of α as well

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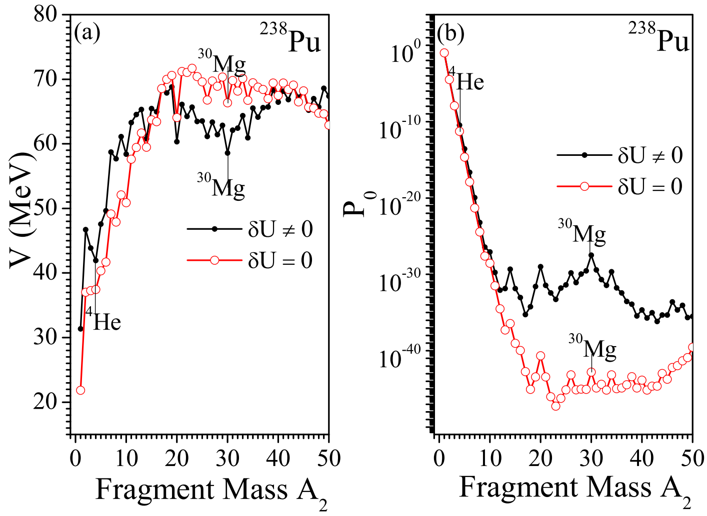

FIG. 1: a) The fragmentation potential, V(MeV) and (b) the P_0 as a function of fragment mass A for the ground state decay of radioactive parent nucleus ^{238}Pu, with and without shell corrections, for spherical consideration of the fragment nuclei.

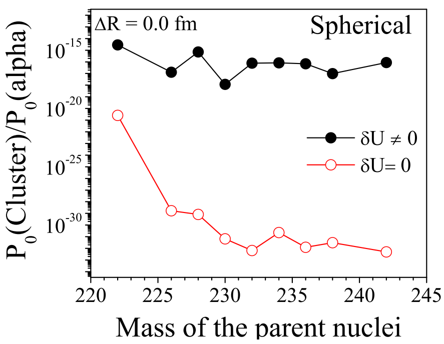

FIG. 2: The variation of, relative values of preformation probabilities for the cluster and α decays, P_0^C/P_0^α with mass of the parent nuclei.

as cluster nucleus ^{30}Mg is strongly minimized with the inculcation of δU only. Fig.1 (b) further explored the fact that ^{30}Mg cluster is highly preformed in the presence of shell corrections, but as the δU are removed other neighboring fragments starts competing with it. Moreover, we see that preformation profile of α decay is not affected much with and without inclusion of shell corrections, comparatively. This shows that the δU affects the cluster emission ^{30}Mg alongside doubly magic ^{208}Pb daughter nucelus.

Fig.2 presents the variation of P_0^C/P_0^α with mass of the parent nuclei, with and without shell corrections included in the calculations. It is interesting to note here that the value of P_0^C/P_0^α with shell corrections included is much more than that of without shell corrections. It is due to the fact that the preformation probability of all the emitted clusters, from their resective parent nuceli, decreases without δU. However, the ratio increases with increase in the mass of the parent nuclei with δU included. Further work is in progress.

References

[1] H. J. Fink *et al.*, Proc. Int. Conf. on Reactions between Complex Nuclei, Nashville, USA, June 10-14, **2**, 21 (1974); R. K. Gupta, *et al.*, Proc. Int. School on Nucl. Phys., Predeal, Romania **75**, 1974.

[2] S. K. Arun *et al.*, PRC **79**, 064616 (2009).

[3] M. Kaur *et al.*, AIP proceedings **to be submitted**.

[4] W. Myers and W. J. Swiatecki, Nucl. Phys. **81**, 1 (1966).

[5] R.K. Gupta. et al., PRC 68, 014610 (2003); 71, 014601 (2005); B.B. Singh. et al., PRC 77, 054613 (2008); Ph.D Thesis, Thapar University, Patiala (2009).