Study of fragmentation potential for doubly magic ^{208}Pb daughter cluster radioactivity

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Introduction

The unstable heavier nuclei release energy spontaneously by emitting radiations and particles, the process called radioactivity, namely, alpha, beta and gamma radioactive decays. In addition to these three types of decays, there exists fourth type of radioactivity known as cluster radioactivity (CR), defined as the spontaneous emission of fragments or clusters ($A \geq 4$) heavier than alpha particle but less than a fission fragment. The decays of number of radioactive nuclei in trans-lead region, which lead to doubly magic ^{208}Pb (Z=82, N=126) or neighboring daughter nuclei through emission of various clusters have been explored in many experimental as well as theoretical studies during last 3-4 decades. The shell closure in the atomic nucleus has now been established as the prominent cause of the process of CR.

In present work, the selected CR decays of different trans-lead parent nuclei are investigated within the the collective clusterisation approach of quantum mechanical fragmentation theory (QMFT) [1], specifically, which lead to ^{208}Pb daughter nucleus, always, through emission of clusters ^{14}C, $^{18,20}O$, ^{22}Ne, ^{23}F, $^{24,26}Ne$, $^{28,30}Mg$ and ^{34}Si. A well established QMFT assumes the clusters to be pre-born with certain probability through the fragmentation potential prior to the penetration of potential barrier between the cluster and daughter nuclei. Here, the fragmentation potentials are studied, only, for the CR decays. The fragmentation potential consists of liquid drop part of energy (V_{LDM}) in addition to shell corrections (δU), Coulomb potential (V_c) and proximity or nuclear potential (V_P). In this study, the importance of shell corrections (only) is explored in the process of CR, due to the availability of the binding energy (B) calculations with the contributions of V_{LDM} and δU separated i.e. B = $V_{LDM} + \delta U$ [2], within the Strutinsky renormanlization procedure [3]. The shell corrections are calculated using the empirical formula of Myers and Swiatecki [4]. The investigation shows that the fragmentation potential contains the significant nuclear structure information of the nuclear system, and its decaying fragments, with the inclusion of δU. The results explored that the δU along

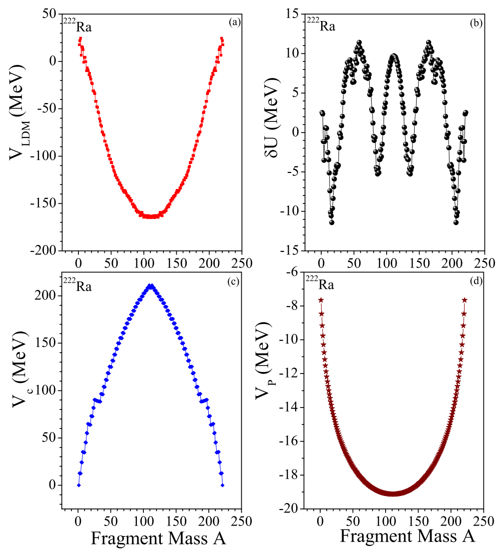

FIG. 1: The variation of (a) shell corrections (δU) (b) liquid drop potential energy (V_{LDM}) (c) Coulomb Potential (V_c) (d) proximity potential (V_P) with fragment mass A for the ground state decay of parent nucleus ^{222}Ra.

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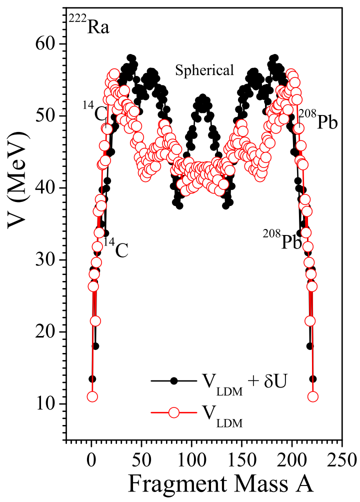

FIG. 2: The fragmentation Potential V(MeV) as a function of fragment mass A for the ground state decay of parent nucleus ^{222}Ra with and without shell corrections.

with V_{LDM} plays a crucial role to have proper understanding of the process of CR.

Methodology

The decay constant in the QMFT based PCM [5] is defined as,

$$\lambda = \nu_0 P P_0. \quad (1)$$

Here ν_0 is the impinging frequency with which the cluster hits the barrier and P_0 is the probability of finding the mass fragmentation η at a fixed R on the decay path. The structure information of the parent nucleus enters through the preformation probability P_0 which inturn depends on the fragmentation potential $V_R(\eta, T = 0)$, calculated as

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

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

Calculations and Discussions

Fig.1 shows the behaviour of various types of potential with fragment mass A. Here, we note that the V_{LDM}, V_c and V_p show the smooth behaviour either fall or rise in their values with varying A of the product nuclei. But the variation of δU with fragment mass A in Fig.1(b) shows that there are minima's existing for the fragments. Most importantly, we find that the structure of the fragmentation potential is due to shell corrections which is shown in Fig.2 by adding all these contributions, with (filled black circles) and without (hollow red circles) including the shell corrections. Quite evidently, the potential energy surface get its significant minima after the inclusion of the shell corrections only.

We find that the emitted cluster ^{14}C with ^{208}Pb daughter is strongly minimized with the inculcation of shell corrections. Also, the calculations for other experimentally observed clusters $^{18,20,22}Ne$, $^{24,26}Ne$, $^{28,30}Mg$ and ^{34}Si along with doubly magic ^{208}Pb daughter nucleus, in the decay of different trans-lead parent nuclei, are strongly minimized with the inclusion shell corrections in the fragmentation potential. It is to be noted here that the fragmentation potential has been calculated for spherical consideration of the fragments.

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