Role of surface energy coefficients in cluster decay

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Introduction

Radioactive heavy nuclei reaches stable region by emitting clusters, apart from emitting α particle, which are heavier than α particle and lighter than the lightest fission fragment, a phenomenon named cluster radioactivity. Poenaru and Greiner [1] interpreted the equivalence between the fission model and preformed cluster model, by stating that the preformation probability in fission models can be considered as the penetrability of the pre-scission part of the barrier. Shi and Swiatecki [2] estimated the half-lives of cluster emission by using a interpolation formula for fused region and a combination of proximity and Coulomb potential for the post-contact region. Proximity potential plays a vital role in deciding the characteristics quantities of a decay. We have analysed the role of nuclear surface energy coefficients in Shi and Swiatecki model in estimating pre-formation probability and half-lives in cluster decay.

Shi and Swiatecki [2] used Coulomb plus proximity potential for the post-touching region and for the pre-touching part they have used power law as given below:

\[ V(L) = \frac{Z_1 Z_2 e^2}{R} + V_P - Q, \quad L \geq L_c \] (1)

\[ V(L) = a(L - L_0)^x, \quad L_0 \leq L \leq L_c \] (2)

where L indicates the extreme extension of the configuration with \( L_c \) corresponds to the contact of the fragments. \( a \) and \( x \) are calculated using smooth continuity relation between the potentials of pre and post touching regions. \( V_P \) is the nuclear proximity potential term given as

\[ V_P = 4\pi R^2 b \Phi(\xi). \] (3)

\( \Phi(\xi) \) is the universal function of proximity potential and \( \bar{R} \) is the mean curvature radius of the reaction partners, characterising the gap. Nuclear surface energy coefficient is given by

\[ \gamma = \gamma_0 \left[ 1 - k_s \left( \frac{N - Z}{A} \right)^2 \right] \text{MeV fm}^{-2}, \] (4)

Here \( \gamma_0 \) and \( k_s \) are parametrised by different authors [3]. Half-life is given by

\[ T_{1/2} = \frac{\ln 2}{\nu P_0 P} \] (5)

Here \( \nu \) is assault frequency and \( P_0 \) indicates pre-formation probability which is the penetrability for the pre-touching region and \( P \) penetrability for the post-touching region; both the penetrabilities are calculated using WKB method.

Results and discussions

We have incorporated, the idea of Poenaru et al [1], i.e. considering the penetrability for the pre-touching region as pre-formation probability, in Shi and Swiatecki [2] model for different parametrization of nuclear surface energy coefficients. Shi and Swiatecki does not include preformation probability in his model. Experimentally identified 15 cluster emitters with 221 ≤ A ≤ 242 are considered for study with emitted clusters such as \(^{14}\text{C},^{20}\text{O},^{24}\text{Ne},^{28}\text{Mg} \) and \(^{32}\text{Si} \) [4]. Based on the advancements in theory and experiments, the
values of $\gamma_0$ and $k_s$ of nuclear surface energy coefficients were parametrised. Here we have used two parameter sets $\gamma_0 = 1.01734$ MeV/fm$^2$, $k_s = 1.79$ denoted as $\gamma$-MS66 and $\gamma_0 = 0.9517$ MeV/fm$^2$, $k_s = 1.7828$ denoted as $\gamma$-MS67 [3]. These values enter the calculation of $P_0$ in the proximity potential through continuity equation. Shi and Swiatecki employed $\gamma$-MS67 in his work. Fig. 1 represents the $P_0$ values calculated using WKB integral for the use of potential given by Eq. (2) for the use of these two $\gamma$’s. From the structure of $P_0$, it is clear that, it decreases as the size of the cluster increases, indicating the size dependence of the $P_0$ in cluster decay. This structure resembles Fig. 3 of our previous work (Ref. [4]) which is the discrepancy between experimental and calculated half-life assuming $P_0$ as 1. However magnitude of $P_0$ differ due to the calculation in the penetrability factor for the post touching region in both the models. Preformation probability values due to use of $\gamma$-MS67 are found to be lower than that calculation due to $\gamma$-MS66. Half-life is calculated for these 15 parent nuclei for cluster decays using Eq. (5) with $P_0$ due to both $\gamma$’s. In Fig. 2 calculated half-lives and experimental half-lives are presented. Solid circle represents the experimental half-lives and open circle and open triangle represent the calculations due to $\gamma$-MS67 and $\gamma$-MS66 respectively. For the use of $\gamma$-MS67, experimental and calculated half-lives coincides for $^{14}$C decay from $^{222}$Ra, $^{24}$Ne decay from $^{232}$U. In the case of $\gamma$-MS66, better matching between experimental and calculated half-lives are noted, for the emission of $^{14}$C from $^{224}$Ra, $^{225}$Ac and $^{226}$Ra and $^{28}$Mg from $^{234}$U, $^{32}$Si from $^{238}$Pu.

References