Study of cluster emission process in view of different binding energy sets

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Introduction

After the successful theoretical prediction by Sȃndulescu [1] and experimental confirmation by Rose and Jones [2], the phenomenon of cluster radioactivity has been studied extensively. It is an intermediate process between α-decay and spontaneous fission. So far, the clusters with mass numbers 14 to 50 have been known to be emitted from various parents in the region ^{221}Fr to ^{252}Cf [3, 4]. Nuclear masses and related deformations of the emitted nuclei affect the cluster emission significantly, as their influence begins at the early stage of preforming the individual clusters inside the parent nuclei within the collective clusterization approach. Since the origin of Bethe-Weizsäcker mass formula, different mass predictions and deformation tables have been proposed. One such formulation has been given by Moller *et al.* in 1995 (MN1995) [5], which was revised in 2016 (MS2016) [6]. Both these formalisms are based on the finite-range droplet macroscopic model (FRDM) and the folded-Yukawa single-particle microscopic model. Apart from these, Ning Wang *et al.* in 2010 (NW2010) [7] proposed a semiempirical nuclear mass formula based on the macroscopic-microscopic method in which the isospin and mass dependence of model parameters are investigated. The rms deviation of MN1995 approach with respect to measured nuclear masses is 0.669 MeV [5], which decreases to 0.5595 MeV for MS2016 [6] and further to 0.516 MeV for NW2010 approach [7]. In the present work, the main aim is to investigate the influence of these three different sets of binding energies and deformation parameters namely MN1995, MS2016, and NW2010 on the relative emergence of clusters from different radioactive nuclei.

Preformed Cluster Model (PCM)

The preformed cluster model (PCM) [8] uses the collective coordinates of mass and charge asymmetries $\eta = \frac{A_1-A_2}{A_1+A_2}$ and $\eta_Z = \frac{Z_1-Z_2}{Z_1+Z_2}$, the relative separation R, and the multipole deformations $\beta_{\lambda i}$ and orientations θ_i (i=1,2) of daughter and cluster nuclei which allows to define the decay half-life $T_{1/2}$, or the decay constant λ as,

$$\lambda = \nu_0 P_0 P, \quad T_{1/2} = \frac{ln2}{\lambda} \tag{1}$$

Here, ν_0 is the assault frequency, P_0 corresponds to cluster preformation probability and P is the barrier penetrability calculated within the WKB approximation. The structure information of the decaying nucleus is estimated in terms of P_0 by solving stationary Schrodinger equation in η-coordinate by using the fragmentation potential defined as:

$$V_R(\eta) = -\sum_{i=1}^{2}[B(A_i, Z_i, \beta_{\lambda i}) + V_C(R, Z_i, \beta_{\lambda i}, \theta_i) + V_P(R, Z_i, \beta_{\lambda i}, \theta_i)] \tag{2}$$

Here, B_i(i=1,2) are the binding energies of the two fragments (daughter and cluster) which comprises of macroscopic as well as microscopic components i.e. the shell corrections are contained in the ground-state binding energies as well. Three different choices of binding energies and deformations (β_{2i}) are taken in the present study viz. Möller *et al.* 1995 (MN1995) [5], Möller *et al.* 2016 (MS2016) [6], Wang *et al.* 2010 (NW2010) [7]. θ_i is the orientation angle between the nuclear symmetry axis and the collision Z-axis, measured in the anticlockwise direction. In Eq.(2) V_C and V_P are, respectively, the Coulomb and nuclear proximity potentials for deformed and oriented nuclei.

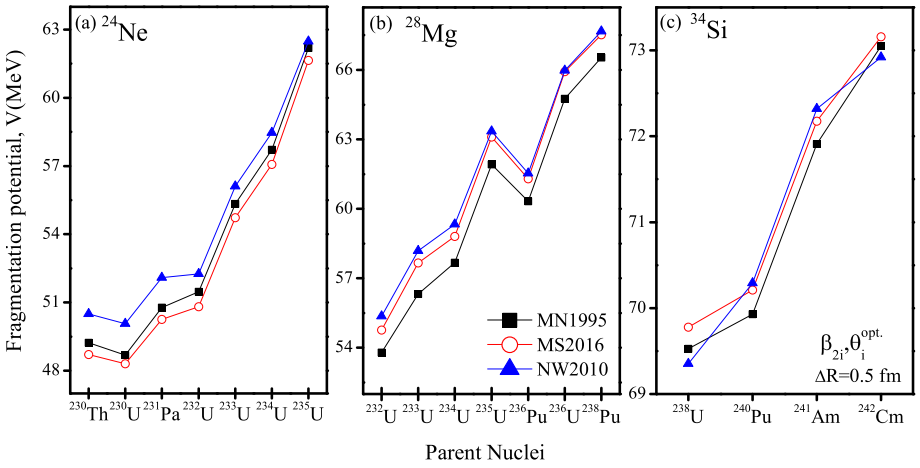

FIG. 1: Fragmentation potential for the emission of ^{24}Ne, ^{28}Mg and ^{34}Si clusters from various parent nuclei (as marked) with the use of various sets of binding energies and deformation parameters namely MN1995, MN2016, and NW2010.

Results and Discussions

In Fig.1, the fragmentation potential for the ^{24}Ne, ^{28}Mg and ^{34}Si clusters emitted from ^{230}Th, ^{231}Pa and ^{230,232,233,234,235}U parent nuclei is plotted using the three different sets of binding energies and deformation parameters namely MN1995, MS2016 and NW2010. The parent nuclei are marked (along horizontal axis) in the figure. The calculations are done at fixed neck-length (ΔR) of 0.5 fm and including the deformation parameters upto order λ=2 (i.e. β_2) using optimum orientations. It is noticed from the figure that the use of different mass tables i.e. MN1995, MS2016, and NW2010 affect the fragmentation potential due to the different binding energies and deformations employed in these formalism. Also, ^{24}Ne is reported to be oblate deformed by MN1995 and MS2016, whereas according to NW2010, it is prolate deformed. ^{28}Mg is prolate deformed, but having different deformation values, whereas ^{34}Si is reported to be spherical in shape by all three formalisms. Alongwith cluster deformations, the daughters also have different shapes or different values of deformations for similar shapes. These changes in the deformation parameters of the clusters and daughters affect the binding energies, proximity potential, Coulomb potential, and hence the fragmentation potential. These changes in the fragmentation potential further affect the preformation probability and hence the decay half-life times of various radioactive decays. Hence from the above study, it is concluded that, the choice of binding energies and related deformation parameters influence the fragmentation potential significantly.

References

[1] A. Săndulescu, D. Poenaru and W. Greiner, Sov. J. Part. Nucl. **11**, 528 (1980).
[2] H.J. Rose and G.A. Jones, Nature **307**, 245 (1984).
[3] R. Bonetti and A. Guglielmetti, Rom. Rep. Phys. 59, 301 (2007).
[4] H.-G. Ortlepp, R. Kotte, and F. Stary, Proc. 15th Int. Symp. on Nucl. Phys., Nuclear Fission, Gaussing, East Germany, Nov. 11-15, 1985, ed. D. Seelinger *et al.*, p.35.
[5] P. Möller, J.R. Nix, W.D. Myers, and W.J. Swiatecki, At. Data Nucl. Data Tables **59**, 185 (1995).
[6] P. Möller, A.J. Sierk, T. Ichikawa, and H. Sagawa, At. Data Nucl. Data Tables **109**, 1 (2016).
[7] N. Wang, M. Liu, and X. Wu, Phys. Rev. C **81**, 044322 (2010).
[8] S.S. Malik and R.K. Gupta, Phys. Rev. C **39**, 1992 (1989).