^{208}Pb-daughter cluster radioactivity using various proximity potentials

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Introduction

The cluster radioactivity is an intermediate process between alpha decay and nuclear fission. Since the theoretical prediction [1] and experimental observation [2] the cluster radioactivity has become a widely studied phenomena. A number of cluster radioactive decays from ^{221}Fr to ^{242}Cm parent nuclei were observed leading to ^{12,14}C, ^{15}N, ^{18,20}O, ^{23}F, $^{22,24-26}$Ne, ^{28,30}Mg, ^{32,34}Si cluster emissions and their respective half-lives have been measured. Recently one of us and collaborators [3] studied the role of deformations and orientation of the nuclei in cluster decays of various radioactive nuclei, particularly for those decaying to doubly closed shell ^{208}Pb daughter nuclei for the first time and then extended the study to the parent nuclei resulting in daughters other than ^{208}Pb. The deformation effect was included with the "optimum" orientation of cold decay process. It may be noted that the optimum cold orientations are good for deformation up to β_2 alone and it was concluded in Ref. [3] that except for ^{14}C decays, the deformations up to β_2 are enough in order to fit the experimental data through the only parameter, namely the neck length parameter 'ΔR', of the Preformed Cluster-decay Model (PCM). However in Ref. [4], it was observed that the deformations up to hexadecapole with use of compact orientations of cold elongated process are good enough for the fitting of half-life of ^{14}C cluster. The related Q-value and angular momentum aspects were also explored in Ref. [4].

It may be noted that till now the pocket formula of Blocki *et. al* is used in the framework of PCM to understand the cluster dynamics. In this work we have used PCM with various version of proximity potentials having different isospin and asymmetry dependent parameters, initially at touching configuration and at a fixed neck length parameter 'ΔR'.

The main aim of this work [5], is to understand the effect of different nuclear potentials on cluster half-lives ($T_{1/2}$), along with possible role of β_2-deformation in ^{208}Pb-daughter cluster radioactivity. The experimental data is taken from Ref. [6].

Preformed Cluster-decay Model

In PCM, the decay constant, and hence the decay half-life time is defined as,

$$\lambda = \nu_0 P_0 P, \qquad T_{1/2} = \frac{\ln 2}{\lambda}. \qquad (1)$$

The preformation (P_0) and penetration (P) probability are calculated within the well-known quantum mechanical fragmentation theory (QMFT), with effects of deformation and orientation degrees of freedom included.

The QMFT is worked out in terms of 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.

The structure information of the decaying nucleus is contained in P_0 via the fragmentation potential, defined for $R = R_a$ ($\geq R_t$),

$$V_R(\eta) = -\sum_{i=1}^{2}\Big[B_i(A_i, Z_i)\Big] + V_C + V_P. \qquad (2)$$

Here V_C and V_P are Coulomb and nuclear proximity potentials for deformed and oriented nuclei. Various different nuclear proximity potentials like Prox 1977, Prox 1988,

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Prox 2000, Bass 1980, CW 1976, BW 1991, Denisov 2002 and mod-Prox 1988, are used here. For more details see Ref. [5]. The WKB tunnelling is $P = P_i P_b$, where P_i and P_b in WKB approximation are

$$P_i = \exp\left[-\frac{2}{\hbar}\int_{R_a}^{R_i}\{2\mu[V(R) - V(R_i)]\}^{1/2}dR\right] \quad (3)$$

and

$$P_b = \exp\left[-\frac{2}{\hbar}\int_{R_i}^{R_b}\{2\mu[V(R) - Q]\}^{1/2}dR\right]. \quad (4)$$

The deformations effect up to quadrupole (β_2) are included with in the "optimum" orientation approach.

Calculations and Discussion

The analysis of ^{208}Pb-daughter cluster radioactivity is worked out at touching as well as at an elongated neck configuration by taking the neck-length parameter ΔR=0.5 fm. It is relevant to mention here that the comparison with experimental data is not good at touching configuration, and it improves significantly at ΔR=0.5 fm as shown in Fig. 1. A wide range of barrier characteristics is covered by using various nuclear proximity potentials. We observe that Prox 1977 and Prox 1988 can reproduce the experimental half-lives very well however the use of mod-Prox 1988 potential seems more reliable for ^{14}C cluster decay. It is clear from Fig. 1 (a) and (b) that Prox 1977 and Prox 1988 are close to the experimental data at R_a=R_T+0.5 fm where as Prox 2000 does'nt work. We have also calculated the standard rms deviation from experimental data and found that for the best two potentials, i.e. Prox 1977 and Prox 1988, it comes out to be respectively 3.70 and 3.72 for spherical and 2.96 and 4.34 for deformed choice of fragmentation. It is worth noting that only the lower limits of half-life is known in case of four clusters (^{15}N, ^{18}O, ^{22}Ne and ^{23}F) among the eleven cases investigated here. These clusters are identified by upper arrow in Fig. 1. The standard rms deviation reported above can be further improved if accurate half-lives of these clusters are measured.

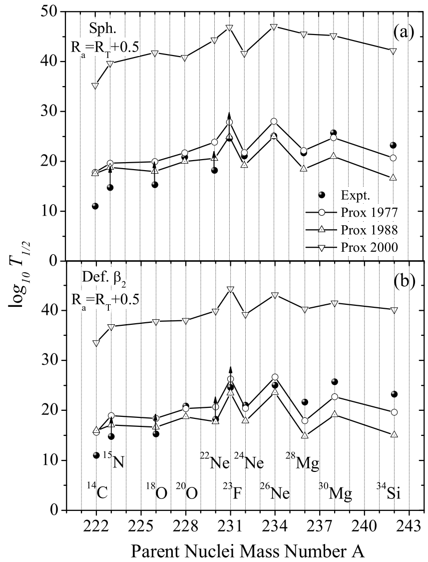

FIG. 1: Comparison of the decay half-lives experimentally observed [6] and the ones which are calculated with PCM [5], for various clusters with ^{208}Pb as the daughter product, using nuclear proximity potentials Prox 1977, Prox 1988 and Prox 2000 at R_a=R_T+0.5 fm for (a) spherical and (b) deformed choice of nuclei.

The barrier characteristics suggests that Bass 1980, CW 1976, BW 1991 may respond equally well for the study of cluster dynamics as their barrier characteristics are closer to Prox 1977 and Prox 1988. The role of higher order deformations and inclusion of non-^{208}Pb-daughter nuclei could be of further interest to associate appropriate proximity interactions to cluster decay process.

References

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