Cluster radioactivity using different types of nuclear proximity potentials

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Introduction

Since the pioneer work of Rose and Jones [1] in 1984, the cluster radioactivity, an intermediate process between α-decay and spontaneous fission, is a widely investigated phenomena, both experimentally as well as theoretically by the physicists all over the world. The real motivation to study this unique and rare phenomena comes from the theoretical predictions [2] of Sandulescu *et.al* in 1980. Since three decades various clusters of different isotopes of C, N, O, F, Ne, Mg and Si are observed experimentally and respective half-lives have been measured [3]. There is still a possibility to explore this phenomena further like the odd-even effects and possible existence of new islands of cluster radioactivity.

Various theoretical models are proposed to explain the cluster radioactivity. The interaction potential is the most critical input of any model. It consists of long range and short range potentials. There are various short range nuclear proximity potentials available in the literature, however it is not clear that which one of the nuclear proximity potential is more appropriate for cluster radioactivity. Recently, me and collaborator [4] studied the ^{208}Pb-daughter cluster radioactivity using different types of proximity potentials. In the present work, this study is extended further to include thirty four ground state cluster decays of parent nuclei to the daughter nuclei other than doubly closed shell ^{208}Pb as well. The effect of deformations is considered up to β_2 only with optimum cold orientations. Various versions of proximity potentials at touching configuration and at a fixed neck length parameter 'ΔR' are used with in the preformed cluster-decay model (PCM). The comparative importance of nuclear proximity potentials Prox 1977, Prox 1988 and Prox 2000 is checked by calculating the standard root mean square (rms) deviation of calculated half-lives from the experimental data [3].

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Preformed Cluster-decay Model

In this model the clusters are assumed to pre-born in the parent nuclei with a certain preformation probability P_0. The decay constant and decay half-life time are defined as,

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

The clusters hit the barrier with impinging frequency ν_0, and penetrate it with penetrability P. If the radius of parent nucleus is R_0 and the kinetic energy of the emitted cluster is $E_2 = \frac{1}{2}\mu v^2$ then ν_0 is given by

$$\nu_0 = \frac{v}{R_0} = \frac{(2E_2/\mu)^{1/2}}{R_0}. \quad (2)$$

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 total interaction potential, at fixed $R = R_a$, is given as

$$V_R(\eta) = -\sum_{i=1}^{2}\Big[B_i(A_i, Z_i)\Big] + V_C + V_P. \quad (3)$$

Here V_C and V_P are Coulomb and nuclear proximity potentials for deformed and oriented nuclei. Various versions of nuclear proximity potentials employed in this work are

TABLE I: Comparison of standard rms deviation of calculated half-lives from experimental half-lives [3] of the various clusters for the nuclear proximity potentials Prox 1977, Prox 1988 and Prox 2000 at R_a=R_T and R_T+0.5 fm.

Proximity	Standard rms deviation (σ)			
	R_a=R_T		R_a=$R_T + 0.5fm$	
	Sph.	Def.	Sph.	Def.
Prox 1977	5.93	4.24	3.54	2.62
Prox 1988	3.93*	2.45*	3.64	4.36
Prox 2000	17.00	18.59	21.65	18.21

*Not calculated for all the clusters considered.

Prox 1977, Prox 1988, Prox 2000, Bass 1980, CW 1976, BW 1991, Denisov 2002 and mod-Prox 1988. For further details see Ref. [4, 5].

The penetrability P in Eq. (1) is the WKB integral between the two turning points R_a and R_b. For the first turning point R_a, the postulate used is

$$R_a(\eta) = R_T(\alpha, \eta) + \Delta R \tag{4}$$

where the η-dependence of R_a is contained in R_T, and the ΔR is a fixed parameter here.

Calculations and Discussion

The 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. In order to observe the effect of deformation, the spherical fragmentation of clusters is also taken into account and the standard rms deviation is compared for the various nuclear proximity potentials (see Table I). It is observed that Prox 1977 reproduces the experimental half-lives very well at ΔR=0.5 fm and improved further as compared to the one obtained in previous work [4]. Hence Prox 1977 comes out to be a better option to study the cluster decay of radioactive nuclei, however the calculated half-lives of ^{14}C-clusters are still bad. The comparison for ^{14}C-clusters improves significantly with the use of mod-Prox 1988 at ΔR=1.0 fm, having stronger isospin and asymmetry dependence, and the standard rms deviation from experimental half-lives comes out to be 1.01 and 1.46 for spherical and deformed choice of fragmentation as is clear from Fig. 1. Also any two or more potentials having similar barrier characteristics will behave similar in the theoretical calculations. This characteristic is utilized here and it is found that BW 1991 and Bass 1980 have barrier characteristics similar to that for Prox 1977 and thus may respond equally well in the study of cluster dynamics. The interaction potential for Prox 1988 and CW 1976 are also similar, so they also show similar behavior. The present study can further be extended to the heavy-particle radioactivity in super heavy nuclei.

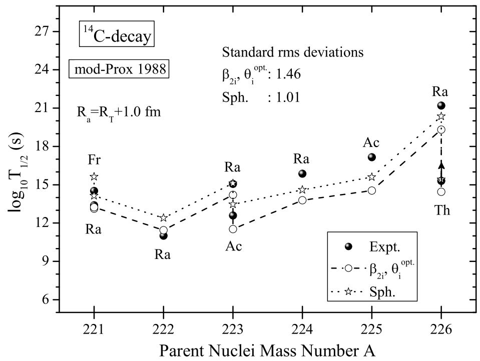

FIG. 1: Comparison of the decay half-lives of experimentally observed ^{14}C-clusters [3] with the calculated ones using nuclear proximity potential mod-Prox 1988 at R_a=R_T+1.0 fm for spherical and deformed choice of nuclei with in the PCM. The parent nuclei are also marked in the vicinity of the half-life symbols. Arrow pointing upward for ^{226}Th shows that the measured half-life is more than the marked point.

References

[1] H. J. Rose and G. A. Jones, Nature **307**, 245 (1984).

[2] A. Săndulescu *et. al*, Sovt. J. Part. Nucl. **11**, 528 (1980).

[3] R. Bonetti and A. Guglielmetti, Romanian Reports in Phys. **59**, 301 (2007).

[4] R. Kumar and M. K. Sharma, Phys. Rev. C **85**, 054612 (2012).

[5] R. Kumar, Phys. Rev. C (submitted).