Phenomenological formula for cluster preformation probability in exotic radioactive nuclear decays

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Introduction

Recently [1], using the preformed cluster model (PCM) of Gupta and collaborators [2], we have deduced the preformation probabilities empirically ${P_0}^{emp}$ from experimental data [3] on both the α and exotic-cluster radioactive decays in the trans-lead region, using the relativistic mean field (RMF) densities [4] in the double folding procedure [5]. For spherical densities, the ${P_0}^{\alpha(emp)}$ for alpha-decays is almost constant $\sim 10^{-2} - 10^{-3}$ for all the parent nuclei studied, and ${P_0}^{c(emp)}$ for cluster-decays of the same parents decrease with increasing size of cluster. The results obtained [1] for both ${P_0}^{\alpha(emp)}$ and ${P_0}^{c(emp)}$ are in reasonable agreement with the empirical formula of Blendowske and Walliser (BW) [6], which leads us to propose here a new phenomenological formula for ${P_0}^{c(emp)}$. The use of deformed RMF densities, however, tend to bring the results closer to the BW formula.

Methodology

The RMF model [4] is used to calculate the nuclear matter densities for the cluster and daughter nuclei, which when folded [5] with the M3Y interaction-plus-a zero-range pseudo-potential representing the single-nucleon exchange effects (M3Y+EX), gives the nuclear interaction potential $V_n(R)$. Adding Coulomb potential $V_C(R)$ ($=Z_d Z_c e^2/R$) results in cluster-daughter interaction potential $V(R)$ ($=V_n(R) + V_C(R)$), used for calculating the WKB penetrability P, representing relative motion. Then, in PCM, the decay constant λ or half-life time $T_{1/2}$ is defined as [2],

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

with the assault frequency $\nu_0 \sim 10^{21}\ s^{-1}$ for all the α- as well as cluster-decays [3]. An empirical estimate of the pre-formation factor P_0 can be obtained [2] as: ${P_0}^{emp} = \frac{\lambda_{Expt}}{\nu_0 P}$, from the experimental λ_{Expt} and calculated $\nu_0 P$.

Calculations and Discussions

Fig. 1(a) illustrates the total interaction potentials V(R) for ^{24}Ne decay of ^{232}U, for both the cases of spherical and deformed nuclei. The penetration path with an energy equal to the Q-value of decay is also shown here. Apparently, for deformed nuclei, the barrier is lowered and hence P increased. The deformation effects of nuclei are recently shown to be important for cluster decay studies [2].

Fig. 1(b) shows the results of our calculation for both the ${P_0}^{\alpha(emp)}$ and ${P_0}^{c(emp)}$, as a function of cluster (and parent) mass, for use of spherical nuclei, as well as the ${P_0}^{c(emp)}$ for some cases with deformation effects included (see, details in [1] for the use of spherical nuclei). The (spherical) ${P_0}^{c(emp)}$ match the BW [6] results reasonably well, within two to three orders of magnitude. However in going from spherical to deformed nuclei, $P_0^{c(emp)}$ also change by about the same order of $\sim 10^{-2}$, and hence bring our $P_0^{c(emp)}$ results closer to BW results [6], as is shown in Fig. 1(b) for the few cases studied here.

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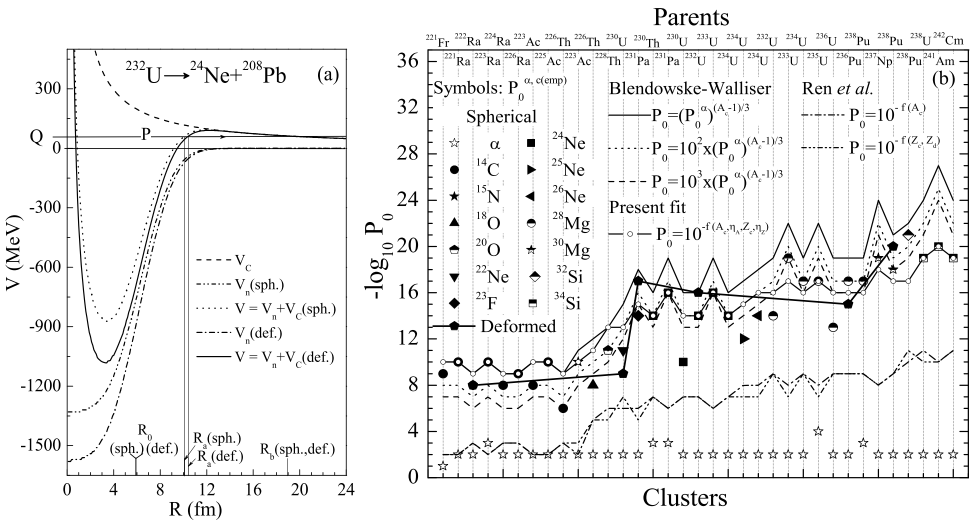

FIG. 1: (a) The double folded M3Y+EX potential $V_n(R)$ for the considerations of spherical and deformed nuclei, the Coulomb $V_C(R)$ and the total interaction potential $V(R)$ for both the spherical and deformed nuclei. (b) The (spherical) ${P_0}^{\alpha(emp)}$ for α- and (spherical/ deformed) ${P_0}^{c(emp)}$ for cluster-decays from various parents (symbols) compared with the other calculations due to empirical formulae and the present fit to (spherical) ${P_0}^{c(emp)}$.

The BW formula [6] is in terms of cluster mass A_c alone, and that the other empirical formulae due to Ren *et al.* [7], which are in terms of either the A_c or Z_c, Z_d, deviate from our calculations by a large order. In the followin, we propose a new empirical formula for ${P_0}^{c(emp)}$, based on two observations: (i) P_0 decreases with the increase in the size of the cluster, and hence must be a function of both A_c and Z_c, (ii) the same cluster is emitted from different parents, and different clusters from the same parent, which means to suggest that the new formula must also contain dependences on mass and charge asymmetries, $\eta_A = (A_d - A_c)/A$ and $\eta_Z = (Z_d - Z_c)/Z$, similar to the new semi-empirical formula for $T^c_{1/2}$ in Ref. [8]. Our proposed empirical formula is

$$ {P_0}^{c(emp)} = 10^{-f(A_c, Z_c, \eta_A, \eta_Z)} \qquad (2) $$

where $f = 1.245 A_c \eta_A - 1.201 Z_c \eta_Z - d$,

d=0 or 1.2, respectivley, for even-A or odd-A parents. Fig. 1(b) shows that this function fits the data better than other empirical formulae [6, 7]. Comparing with the empirical formula for $log_{10} T^c_{1/2}$ in [8], it is evident that the penetrabilty P represents the Q-value alone, i.e., $log_{10} T^c_{1/2} \propto Q^{-1/2}$, and hence ν_0 a constant.

Summary

A refined empirical formula is proposed for ${P_0}^{c(emp)}$, which has its bearing on the earlier published semi-empirical formula for $T^c_{1/2}$ values [8]. However, the deformation effects of the RMF densities are still to be studied in detail.

References

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