Influence of magicity on cluster decay half-lives of $^{112-118}$Ba isotopes

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Introduction

As a phenomenon, cluster decay was discovered in 1980 by Sandulescu [1] as a spontaneous decay involving the emission of clusters heavier than ^{4}He. It was experimentally established by Rose and Jones [2] where ^{14}C was emitted from ^{223}Ra. Since then, about thirty more clusters have been observed, ranging from ^{14}C $-$ ^{34}Si. Usually, cluster radioactive decays are associated with double magic daughter nuclei like ^{100}Sn and its neighbours. Such nuclei, especially those around the neutron shell closure exerts a certain influence on the decay half-life.

The decay half-life is estimated using the preformed cluster model (PCM) which is based on the quantum mechanical fragmentation theory (QMFT) [3]. The PCM assumes that the clusters are pre-born within the parent nucleus before their barrier penetration (formed from the superposition of the Coulomb and nuclear potential). To deduce the nuclear potential, the phenomenological M3Y nucleon-nucleon (NN) potential is folded the densities obtained from the relativistic mean-field (RMF) Lagrangian, following the double folding technique [4]. As a result, the nuclear interaction potential and the Coulomb potential $V_C(R) = Z_c Z_d e^2/R$ combines to give the total interaction potential which is further employed to obtain the WKB penetration probability P within the PCM.

In the present study, the neck-length parameter which incorporates the neck-formation effect and determines the first turning point within the PCM is fixed at $\Delta R = 0.5$ fm, which is suitable for cluster decay. The Q-values are estimated from the RMF (NL3*) and are compared with the available experimental data (Q_{AME03}) [5]. The role of magicity on cluster decay half-lives is investigated, considering ^{12}C emission of $^{112-118}$Ba isotopic chain.

Theoretical formalism

The non-linear RMF Lagrangian density used for the description of the interactions between the many-body system of nucleons and mesons is given in Ref. [6]. The effective M3Y NN interaction plus the single nucleon exchange effect is given as [4]

$$V_{\rm eff}^{M3Y}(r) = 7999\frac{e^{-4r}}{4r} - 2134\frac{e^{-2.5r}}{2.5r} + J_{00}(E)\delta(s). \quad (1)$$

with the ranges in fm and strength in MeV. The decay constant and half-life is calculated within the PCM [3] as

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

Here, P is calculated from the WKB approximation and the preformation P_0 is calculated from the well-known Blendowske & Walliser scaling factor [7].

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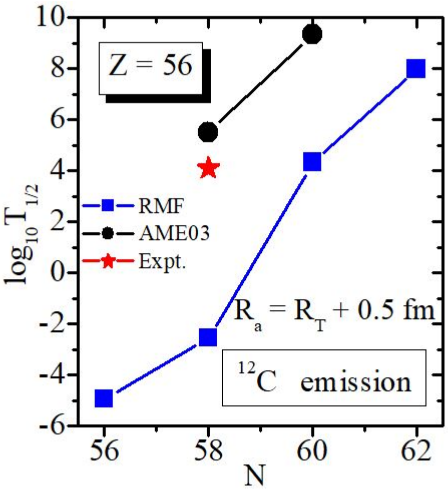

FIG. 1: Predicted logarithmic half-lives of ^{12}C and experimental data [8] as a function of the neutron numbers of the decaying $^{112-118}$Ba isotopes at the $R_a = R_T + 0.5$ fm. Experimental data [8] is also for comparison.

Result and Discussions

The emission of ^{12}C from the parents $^{112-118}$Ba isotopes are considered in the present analysis. Fig 1 shows the plot of the logarithmic half-lives as a function of the respective neutron number of the forementioned decaying parent nuclei leading to double magic daughter and those in its vicinity. From the figure, it is clear that the deepest minima are found at the neutron shell closure $N = 56$, corresponding to ^{100}Sn daughter. Furthermore, it is observed that $\log_{10} T_{1/2}$ increases with the N/Z ratio.

It is important to note that all the considered parent nuclei are in their ground state except ^{118}Ba ($N = 62$) which is in its 1^{st} intrinsic excited state. Interestingly, the inclusion of excitation does not preclude or dominate magicity. In other words, the effect of magicity for the N/Z ratio is maintained despite the consideration of an intrinsic excitation. The predicted $\log_{10} T_{1/2}$ from the available Q_{AME03} are in good agreement with the observed lower limit corresponding to $N = 58$. Comparing the 2^{nd} and 4^{th} columns of Table I, it is apparent that there is an inverse relationship between the decay energy Q_{RMF} and the logarithmic half-lives. As such, the decay energy decreases with increasing the N/Z ratio. Although, the half-lives of the region under study is not precisely known as yet, the M3Y prediction for AME03 agrees with the experimental lower limit of ^{114}Ba ($N = 58$).

TABLE I: M3Y predicted half-lives for ^{12}C decay of $^{112-118}_{56}$Ba isotopes at the $R_a = R_T + 0.5$ fm.

	Q-values (MeV)		$\log T_{1/2}$		
N	Q_{RMF}	Q_{AME03}	RMF	AME03	Expt.[8]
56	27.50		-4.94		
58	24.46	18.99	-2.56	5.51	> 4.10
60	19.44	17.03	4.32	9.32	
62^a	17.49		7.97		

^{a}in the 1^{st} excited state

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