Evolution of preformation probability of alpha particles in the decay of trans-lead nuclei 83≤Z≤92 with N=126

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Introduction

An alpha(α)-decay, one of the important decay channel of unstable nuclei, has been proven to be tool to investigate the exotic nuclei in the closed shell region and drip-line as well as super heavy region. For example it provides a reliable method to identify new synthesized super heavy elements and isomeric states [1] and it has been used to find triplet of differently shaped states in the vicinity of the Z=82 shell closure [2]. Although α-decay is one of the oldest phenomenon in the nuclear physics, above mentioned studies are hot topics in the subject during recent times. The α-decay theory was explained by Gamow and, Gurney and Condon independently on the basis quantum tunneling [3], since then different approaches has been proposed to achieve a microscopic description of alpha decay. An alpha cluster preformation probability contains significant information about nuclear structure. However, it is often insufficient to describe the actual situation of alpha cluster preformation even on large shell model basis consequently, which lead to two theoretical approaches, BCS method in combination with shell model and hybrid model having shell model wave function supplemented with a cluster component [4]. Due to complexity of nuclear many body problem it is difficult to extend microscopic calculations within hybrid model, especially for nuclei away from the magic shell.

In the present work we intend to investigate the α-decay of trans-lead nuclei 83≤Z≤92 with N=126 using preformed cluster decay model (PCM) of Gupta and Collaborators which is based on quantum mechanical fragmentation theory (QMFT) [5]. It would be quite interesting to study the dynamical evolution of alpha cluster preformation probability $P_{0\alpha}$, within collective clusterization approach of PCM, in this closed shell region with the proton number gradually moving away from Z = 82 proton shell closure. The PCM calculated results will be compared with the available experimental data for the decay half-time of the parent nuclei under study. Moreover, value obtained by Blendowske and Walliser (BW) [6] for $P_{0\alpha} = 6.3\times10^{-3}$, will also be compared with the PCM results.

Methodology

Within PCM, the ground state decay of a parent nucleus is worked out in terms of coordinates of QMFT i.e. mass asymmetry $\eta = (A_T\text{-}A_P)/(A_T+A_P)$ and relative separation R. In terms of these collective coordinates, the decay constant is defined as

$$\lambda = \frac{ln2}{T_{1/2}} = \nu P_0 P. \quad (1)$$

Where, preformation probability P_0 refers to η motion which we get by solving of stationary Schrodinger wave eq. in η. As shown in Fig. 1, the penetrability P refers to R motion and is calculated using the following equation

$$P = P_i W_i P_b \quad (2)$$

where $W_i = \exp(-bE_i) = 1$ is called the internal de-excitation, P_i and P_b are calculated using WKB approximation. R_a, R_i and R_b are the turning points. Also, R_t=R_1+R_2, R_a=R_t+ΔR and ΔR is the neck length parameter.

Calculations and discussions

Table 1 presents the PCM calculated $P_{0\alpha}$, α penetration probability P_α, decay constant λ

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TABLE I: : The PCM calculated $P_{0\alpha}$, P_α, λ and $T_{1/2}$ and their comparison with the experimental values for α-decay of the trans-lead parent nuclei 83≤Z≤92 with N=126, alongwith fitted ΔR values.

Parent	*Daughter*	ΔR (fm)	P_0	P	Q (MeV)	λ (s^{-1})	PCM $T_{1/2}$ (s)	Expt. $T_{1/2}$ (s)
^{210}Po	^{206}Pb	0.920	1.15×10^{-9}	9.45×10^{-21}	5.2	2.47×10^{-8}	2.70×10^{7}	1.19×10^{7}
^{212}Rn	^{208}Po	0.775	9.30×10^{-9}	2.12×10^{-17}	5.0	2.47×10^{-4}	1.37×10^{3}	1.43×10^{3}
^{214}Ra	^{210}Rn	1.090	1.21×10^{-8}	7.95×10^{-15}	7.2	2.56×10^{-1}	2.69	2.46
^{216}Th	^{212}Ra	1.458	3.29×10^{-7}	2.60×10^{-14}	7.8	2.30×10^{1}	2.89×10^{-2}	2.89×10^{-2}
^{218}U	^{214}Th	1.195	4.09×10^{-7}	3.91×10^{-13}	8.3	4.54×10^{2}	1.52×10^{-3}	1.51×10^{-3}

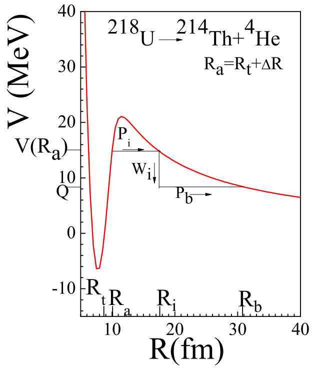

FIG. 1: The variation of scattering potential V(MeV) with R for the α-decay of ^{218}U.

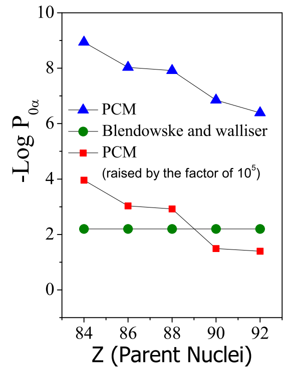

FIG. 2: The $P_{0\alpha}$ as a function of Z of the trans-lead parent nuclei.

and half life time $T_{1/2}$ for α-decay of the trans-lead parent nuclei 83≤Z≤92 with N=126. We see here that $P_{0\alpha}$ as well as $P\alpha$ increases with increasing Z i.e. as moving away from the shell closure Z=82. Consequently, increase in the λ for the α-decay of the parent nuclei and fall in the value of $T_{1/2}$ i.e. the stability of the parent nuclei decreases with increasing Z. The results for the PCM calculated $T_{1/2}$ are also very well compared with the experimental data. Fig. 2 also gives the $P_{0\alpha}$ as a function of atomic number Z of the trans-lead parent nuclei. It is quite evident here that with the increase in the Z the $P_{0\alpha}$ increases (blue triangle). The results are compared with the BW prediction (green circle), which is estimated as constant value, as given in the introduction, for the $P_{0\alpha}$ for even-even parent nuclei.

Though, here, we are successful in analyzing the variation of $P_{0\alpha}$ for the trans-lead parent nuclei 83≤Z≤92 with N=126, the PCM calculated values are deviated almost by the factor of 10^5 (red square, fig. 2) from BW prediction. It is pointed here that the present calculations have been done for the spherical consideration of nuclei and the results demand for the inclusion of effects of deformation and orientation of nuclei in the same. Work is in progress.

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