Competing modes of α and one-proton radioactivities in proton emitter ^{185}Bi nucleus

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Introduction

The exploration of the structure of atomic nucleus was stimulated with the discovery of radioactivity. In the ensuing decades, the study of different nuclear decay modes as well as nuclear reactions remain the indispensable tool to probe nuclear structure and to investigate the limits of nuclear stability within nuclear landscape. In 1960, Goldansky predicted the existence of new type of nuclear decay mode in proton (p) rich nuclei [1]. Particularly, at proton drip line, the limit of nuclear binding for p-rich nuclei, one-proton ($1p$) and two-proton ($2p$) radioactivity were expected to occur. The one-proton radioactivity (OPR) was confirmed experimentally in 1970 by Jackson et al. [2]. Now a days, OPR is an established decay mode of odd-Z elements and a wealth of experimental data of proton rich nuclei with 50 < Z < 84, i.e., between Sn and Bi regions are available [3]. The emission of proton depends strongly upon the Q-value and its positive value portrays spontaneous p-emission, i.e., OPR from these proton rich nuclei. These studies help to obtain structural information and the related aspects of the nuclei beyond the stability line towards proton drip line in nuclear landscape.

Several developments on theoretical front have been made to explain the experimental observations of OPR. Different theoretical approaches such as the effective liquid-drop model [4], unified fission model (UFM) with proximity potential [5] and double-folding model [6] have been used to explore the same. The decay of p-rich ^{185}Bi nucleus has been explored within UFM approach with spherical consideration and assuming $P_0 = 1$ [5] for $1p$ emission. However, in the present work we tend to investigate the α emission as competing mode in proton emitter ^{185}Bi nucleus, within collective clusterization approach of preformed cluster-decay model (PCM), with effects of deformation and orientation (cold, elongated configuration) of outgoing nuclei included [7]. The comparison of PCM calculated half-lives, for spherical and quadrupole deformation (β_2) considerations has also been carried out, for $1p$ and α emissions.

Methodology

The PCM [7] uses the dynamical collective coordinates of mass and charge asymmetries η and η_z on the basis of quantum mechanical fragmentation theory. The decay constant in PCM is defined as

$$\lambda = \nu_0 P_0 P \quad (1)$$

$$T_{1/2} = ln2/\lambda \quad (2)$$

Here, ν_0 is the impinging frequency with which the cluster hits the barrier. P is the barrier penetrability and P_0 is cluster preformation probability which refer, to the R and η-motions, respectively. Then, for all the clusters P_0 is given by

$$P_0(A_i) = \mid \psi(\eta(A_i)) \mid^2 \frac{2}{A}\sqrt{B_{\eta\eta}} \quad (3)$$

which is given by solution of stationary Schŕodinger eqn. in η co-ordinate. The fragmentation potential $V_R(\eta)$ is calculated as the sum of Coulomb interaction, the nuclear proximity potential and the ground state binding energies of two nuclei.

Calculations and discussions

Fig.1 shows the preformation profile of all the competing fragments in the decay of ^{185}Bi

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TABLE I: The decay half-lives $T_{1/2}$ for OPR and α radioactivity, calculated within PCM for decay of ^{185}Bi, compared with experimental data [8].

Decay mode	Q value	PCM				Expt.
		Spherical		Def. β_2		
		ΔR (fm)	$log_{10}T_{1/2}$	ΔR (fm)	$log_{10}T_{1/2}$	$log_{10}T_{1/2}$
p+^{184}Pb	1.624	0.958	-6.604	0.959	-6.620	-4.229
α+^{181}Tl	7.639	0.774	-3.466	0.70	-3.487	-3.477

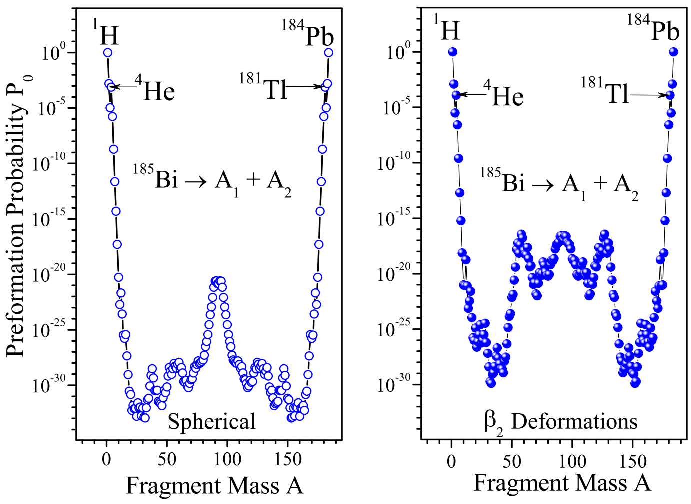

FIG. 1: The relative P_0 of 1p and other clusters in the decay of ^{185}Bi with (a) spherical and (b) β_2 deformed, oriented nuclei.

nucleus, with a) spherical and b) deformed (β_2) and oriented, nuclei configurations. We notice that 1p-emission is more probable than α-emission for both the cases. It may be due to shell closure effect of Z=82 daughter nucleus in case of OPR. Moreover, with β_2 considerations, the P_0 for α is further relatively reduced compared to spherical case. The PCM calculated half lives ($T_{1/2}$) is obtained by adjusting the only parameter, neck-length parameter ΔR, given in Table I.

It is important to note that the value of ΔR is more for 1p-emission compared to α-emission, which indicates that the later follows the former. The results are nearly same for both the considerations. For α decay, the calculated $T_{1/2}$ is in good agreement with the experimental data [8], while for 1p-emission there exists deviations, and thus it will be interesting to explore the role of higher orders of deformations in the PCM calculated $T_{1/2}$ of proton and α decays. Furthermore, a systematic study should be developed for calculated $T_{1/2}$ of 1p-emission in other proton emitters, within the collective clusterization approach of PCM, which undertakes exploration of significant structural information of decaying nucleus via P_0 of all clusters before tunneling of confining potential barrier.

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