Half-lives of deformed proton emitters in the medium mass region

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Introduction

Proton radioactivity offers a definite probability to get wealthy information about the nucleus located beyond the proton drip line. To directly study ground state proton emitters, however, one must look at nuclei with half lives in the range of 1 μs to 1 s, to which current experimental capabilities are geared to handle. This has made one to look at heavier elements with Z > 50. We give a description of the theoretical framework used to identify the proton emitters involving separation energy calculation and exotic decay model which is used to calculate the half-life of the known proton emitters. Then we give the formalism of the microscopic model namely the Triaxially Deformed Cranked Nilsson Strutinsky Shell Correction method. This model gives the role of normal and quadrupole deformations observed in the possible proton emitters. The novel idea used here is plotting the *Potential Energy Surfaces (PES)* for the shape calculations in the proton emitters.

Theoretical formalism

For proton radioactivity, a finite range Yukawa plus Exponential potential along with the Coulomb potential proposed by Shanmugam and Kamalaharan model [1] is used for the post scission region and a third order polynomial is used for the overlapping region. While the centrifugal barrier has negligible role to play in cluster radioactivity, it becomes appreciable in the case of alpha decay. For proton emission the centrifugal effect should become very much considerable. Hence a centrifugal barrier is added to the post scission region for considering proton radioactivity. Here the parent is considered to be deformed and so to include the deformation effects, spheroidal deformation β_2 and Nilsson's hexadecapole deformation β_4 are considered [2,3].

Results and discussions

The half-life of proton decay strongly depends on the energy of the proton, means the Q-value of the reaction. As the Q_p value changes from 0.5 to 2.0 MeV, the half-life changes by more than 22 orders of magnitude, from 10^{10}s to 10^{-12} s and are clearly visible from the Fig. 1. This shows the strong dependence of the lifetime on Q_p falling several magnitudes with a small change in Q-value. It obviously shows that the ground state emission will not be observed immediately after drip line because when Q_p is less, the half-life is dominated by β^+ decay. For small values of Q_p, proton emission half-lives are very long and the total decay is dominated by beta decay. From the Fig. 1, the Q-value which gives rise to proton emission increases with increase in nuclear charge. For light nuclei it is found to be 0.5 MeV and for heavy nuclei it is almost nearing 2 MeV.

Table 1: Calculated Half-life of Ho isotopes

Nucleus	β_2	Calculated Half-Life (s)	Reference Half-Life (s)
Ho^{140}	0.275	1.07×10^{-4}	1.156×10^{-4}
Ho^{141}	0.28	18×10^{-6}	11×10^{-6}
Ho^{142}	0.23	2.31	2.187

To find the deformation effect of proton emitters the PES graphs are powerful tool to study the shape of the selected nucleus. Fig. 2 shows the potential energy surface of ^{138}Tb ($N \neq Z$ case) at the ground state spin of 1 $\hbar$

having zero temperature. The minimum lies in the prolate region concluding that the ^{138}Tb has normal deformed prolate shape. Significant deformation is obtained in the odd Z nucleus of ^{141}Ho using the cranking model showing the triaxial shape in its ground state. While calculating the half-lives of Holmium isotopes, it is found that ^{140,141}Ho are more deformed (β~0.286) when compared with other Holmium isotopes ^{142,143,145}Ho. The former are found to have shorter half-lives than the other isotopes confirming that deformation enables effective proton emission. Competing minima are found to occur along non-collective oblate and collective prolate lines. At ground state spins, the competition between collective oblate and non-collective oblate states is significant which may cause rotational isomers. Proton emission from ^{141}Ho and ^{131}Eu has recently been observed at the FMA and the decay rates cannot be explained by spherical WKB calculations. These nuclei are predicted to be highly deformed (~0.3). The observation of these and other proton emitters expected to be found in the $57 < Z < 65$ region should greatly increase our understanding of the role of deformation in the proton decay process.

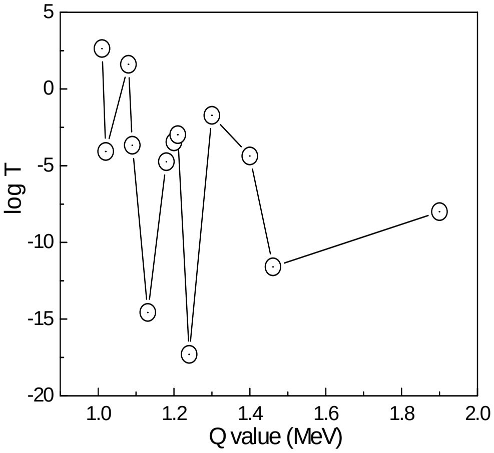

Fig. 1 Variation of half-life as a function of Q value for the medium mass proton emitters

The Table 1 shows the calculated half-lives on comparison with reference half-lives for Ho isotopes. It is found that the SK model used in calculating the half-lives are found to give values in agreement with the compared values [4]. Guzman has calculated the half-lives of various proton emitters by using the effective liquid drop model. He has insisted the role of angular momentum (ℓ) values for the proton decay of different parent nuclei like ^{156}Ta, ^{161}Re, and ^{171}Au. In the present work we have taken $\ell = 2$ for all the selected nuclei and hence there is a mismatch in the half-lives of few emitters discussed in the table as those nuclei are assigned values $\ell = 0, 2, 5, 7$ in the reference calculations. Since the proton is a point charge, the effect of centrifugal potential is important. By comparing the deformation and the half-lives of the isotopes of different proton emitters, it is found that the maximum deformed nucleus is found to have a short half-life.

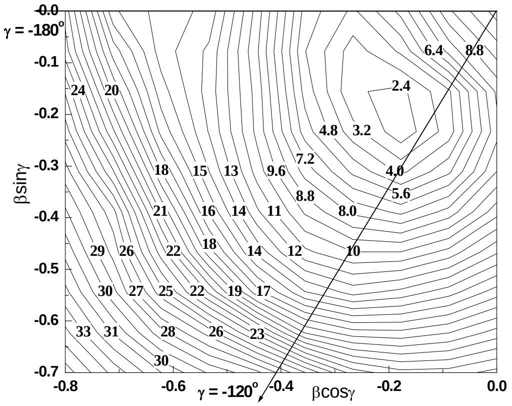

Fig. 2 Prolate shape determination by Potential Energy Surface for ^{138}Tb

Using the calculated separation energy values, new one proton emitters are identified. The region $50<Z<83$ in the periodic table is found to be a fertile region for one-proton emission. Since most of the nuclei are found to have a modest non-zero quadrupole deformation, it is found that calculating half-lives under the assumption that they had spherical shapes wouldn't work.

References

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