Study on the effect of deformation for the emission of $^{19-24}$F neutron halo nuclei via cluster radioactivity

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Introduction

The deviation from the spherical shape of a nucleus is generally termed as nuclear deformation. The concept of nuclear deformation was first introduced by Pauli while explaining the hyperfine splitting of energy levels that results from the electromagnetic interaction of non-spherical nuclei. The nuclear deformation has an important role in determining many of the properties of a nucleus; especially various modes of nuclear decay. In many models, it is considered that the nuclear core maintains a spherical or non-spherical shape with a deformation in the outer layer due to the correlated oscillation of surface nucleons. The nuclear deformation is characterized by the deformation parameter β of different orders: quadrupole (β_2), octupole (β_3), hexadecapole (β_4) deformation etc.

Theoretical studies on the effect of nuclear deformation of parent, daughter and clusters, on the half-life of cluster radioactivity has been conducted by Sandulescu et al [1], Shi and Swiatecki [2], Kumar et.al [3], K P Santhosh et.al [4] and many other researchers using various theoretical models. In the present study we have made an attempt to determine the effect of quadrupole and hexadecapole deformation on the half-life of decay of $^{19-24}$F neutron halo isotopes from $^{292-320}$120 even-even nuclei in the super heavy region using the Coulomb and Proximity Potential Model (CPPM).

The modified form of Coulomb and Proximity Potential Model

For a parent nucleus exhibiting exotic decay, the interacting potential barrier can be written as;

$$V=\frac{Z_1Z_2e^2}{r}+V_p(z)+\frac{\hbar^2 l(l+1)}{2\mu r^2}\ ;\ \text{for } Z>0 \quad (1)$$

where Z_1 and Z_2 are the atomic numbers of the daughter and the emitted cluster, r is the distance between the fragment centers, l is the angular momentum quantum number, μ is the reduced mass and $V_p(z)$ is the proximity potential. The barrier penetrability P is given as;

$$P=\exp\left\{-\frac{2}{\hbar}\int_a^b\sqrt{2\mu(V-Q)}\,dz\right\} \quad (2)$$

where a and b are the turning points given by, $V(a)=V(b)=Q$ and Q is the energy released. The half life time of decay is given by;

$$T_{1/2}=\frac{\ln 2}{\nu P} \quad (3)$$

where $\nu=\frac{2E_V}{h}$, the number of assaults on the barrier per second and E_V is the empirical zero point vibration energy. The Coulomb interaction between two deformed and oriented nuclei with higher order multipole deformation is given by,

$$V_C=Z_1Z_2e^2\frac{1}{r}+$$
$$3Z_1Z_2e^2\sum_{\lambda,i=1,2}\frac{1}{2\lambda+1}\frac{R_{0i}^{\lambda}}{r^{\lambda+1}}Y_\lambda^{(0)}(\alpha_i)\left[\beta_{\lambda i}+\frac{4}{7}\beta_{\lambda i}^2Y_\lambda^{(0)}(\alpha_i)\delta_{\lambda,2}\right] \quad (4)$$

with $R_i(\alpha_i)=R_{0i}\left[1+\beta_{\lambda i}Y_\lambda^{(0)}(\alpha_i)\right]$ (5)

Results, Discussion and Conclusion

Theoretical calculations were done on the effect of quadrupole and hexadecapole deformation on the half-life of decay of $^{19-24}$F neutron halo isotopes from $^{292-320}$120 even-even nuclei in the super heavy region using the

Coulomb and Proximity Potential Model. The Q-values of the reactions are computed using the experimental binding energy data of Audi and Wapstra [5] and the tables of KTUY [6] and the deformations parameters from the nuclear data tables of P Moller et.al [7].

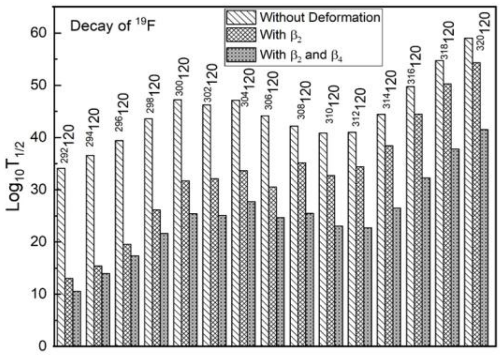

Fig.1 Comparison of computed half-life for the decay of ^{19}F from $^{292\text{-}320}$120 without deformation, with β_2 and with β_2 & β_4 deformations.

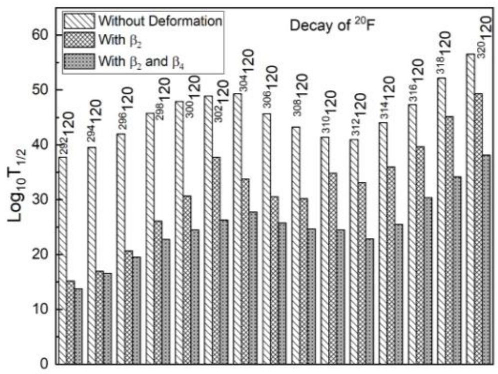

Fig. 2 Comparison of computed half-life for the decay of ^{20}F from $^{292\text{-}320}$120 without deformation, with β_2 and with β_2 & β_4 deformations.

The selected $^{19\text{-}24}$F isotopes have prolate deformation with $\beta_2 > 0$. The parents and respective daughters are also deformed except $^{302\text{-}306}$120 and $^{293\text{-}299}$111. It has been observed that the inclusion of quadrupole deformation has lowered the half-life of decay considerably as it reduces the height and width of the potential barrier and hence increases the barrier penetrability. In the decay of ^{19}F, ^{20}F and ^{21}F, the inclusion of hexadecapole deformation further lowered the half-life of decay and in other cases no such significant effect is observed. A comparison of computed half-lives for the decay of ^{19}F, ^{20}F and ^{21}F from $^{292\text{-}320}$120 is given in figures 1-3. Without deformation, the computed half-lives were well above the experimental limit ($T_{1/2} \le 10^{30} S$) for almost all decays. However, when the quadrupole and hexadecapole deformations are included, the half-life of decay is decreased below the experimental limit and the decay probability is increased. Further it is noticed that the minimum half-life of decay is obtained for the decays in which the daughter neutron numbers are 178 and 184. This confirms the role of neutron shell closure of daughter nuclei for determining the possible decays. Also it is found that the parents without deformation are more stable against the decay as indicated by high value of half-life and the most probable decays correspond to the formation of daughter nuclei without deformation.

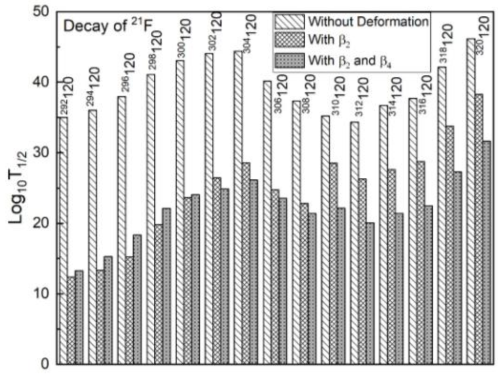

Fig. 3 Comparison of computed half-life for the decay of ^{21}F from $^{292\text{-}320}$120 without deformation, with β_2 and with β_2 & β_4 deformations

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