Study on the Emission of Neutron Rich Exotic Nuclei from Z = 122, 124 and 126 Even-Even Superheavy Nuclei.

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Introduction

Cluster radioactivity is usually observed in trans-lead nuclei and is one of the most discussed phenomena in nuclear physics. Apart from alpha decay, beta decay and spontaneous fission, heavy nuclei can decay via emitting particles heavier than alpha particles and are highly asymmetric spontaneous disintegration. It was predicted in 1980 by predicted by Sandulescu et al. [1] and experimentally confirmed by Rose and Johns [2].

In the present work we have investigated the possibility for the emission of $^{15-21}$N, $^{17-23}$O, $^{19-25}$F and $^{21-28}$Ne neutron rich nuclei from $^{290-320}$122, $^{292-322}$124 and $^{298-326}$126 even-even super heavy nuclei via cluster radioactivity within the framework of Coulomb and Proximity Potential Model [3]. Since the superheavy nuclei may be in a deformed state, we have also investigated the effect of quadrupole and hexadecapole deformation on the decay half-life of the cluster emission. Deformation refers to the deviation from the spherical shape and is characterized by quadrupole, octupole and hexadecapole deformation parameters.

The 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;

$$T_{1/2}=\frac{\ln 2}{\nu P}\text{ , with } \nu=\frac{2E_V}{h} \quad (3)$$

where, ν is 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,

$$V_C=\left\{\begin{matrix}\dfrac{Z_1Z_2e^2}{r}\\ +3Z_1Z_2e^2\sum\limits_{\lambda,i=1,2}\dfrac{1}{2\lambda+1}\dfrac{R_{0i}^{\lambda}}{r^{\lambda+1}}Y_{\lambda}^{(0)}(\alpha_i)\left[\beta_{\lambda i}+\dfrac{4}{7}\beta_{\lambda i}^2Y_{\lambda}^{(0)}(\alpha_i)\delta_{\lambda,2}\right]\end{matrix}\right\}$$

with $R_i(\alpha_i)=R_{0i}\left[1+\beta_{\lambda i}Y_{\lambda}^{(0)}(\alpha_i)\right]$ (4)

where R_{0i} is the normal radius of the nuclei and α_i is the angle between the radius vector and the symmetry axis of the nuclei in the i^{th} site.

Results, Discussion and Conclusion

For the occurrence of cluster radioactivity, the Q-value of the reaction must be greater than zero. The Q-values of the reactions are computed using the tables of KTUY [4] using the expression,

$$Q=\begin{bmatrix}M(A,Z)-M(A_1,Z_1)-M(A_2,Z_2)\\ +k\left(Z_{A,Z}^{\varepsilon}-Z_{A_1,Z_1}^{\varepsilon}\right)\end{bmatrix} \quad (5)$$

The correction term $k\left(Z_{A,Z}^{\varepsilon}-Z_{A_1,Z_1}^{\varepsilon}\right)$ in the Q-value was introduced by V.Y. Denisov et al. [5] to account for the screening effect of the atomic electrons. The barrier penetrability and the half-life of decay were calculated using the Coulomb and Proximity Potential Model. We have plotted the graph of neutron number of the parent verse $\log_{10} T_{1/2}$ and the neutron number of the parent verses $\log_{10} P$, where P is the barrier penetrability. These plots are mirror images to each other. A peak in the plot of neutron number of parent verses $\log_{10} T_{1/2}$ shows the shell closure of the parent nucleus and a dip in the plot shows the shell closure of the daughter nucleus.

For the emission of $^{15\text{-}21}$N isotopes from the selected even-even nuclei, it can be seen that many isotopes have a half-life of decay less than 10^{30} seconds and are possible for emission through cluster radio activity. It is also clear that ^{15}N nucleus has the lowest half-life of decay from all the Z =122, 124 and 126 isotopes and hence it is the most probable nuclei among $^{15\text{-}21}$N to emit via cluster decay (Fig.1). In all plots, there is a peak at parent neutron number 184 and a dip a parent neutron number 192.

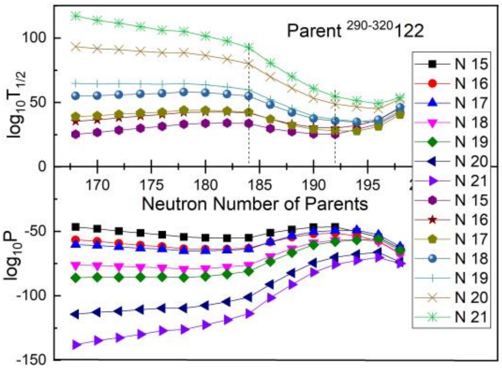

Fig.1: Plot of half-life time and barrier penetrability verses neutron number of the parents for the decay of (a) $^{15\text{-}21}$N from $^{290\text{-}320}$122, $^{292\text{-}322}$124 and $^{298\text{-}326}$126 even-even super heavy nuclei.

The emission of $^{17\text{-}23}$O also shows similar characteristics. The curve has a peak at parent neutron number 184 and a dip at parent neutron number 192. Among the selected oxygen isotopes, ^{20}O shows the lowest half-life of decay from the parents with neutron number 192. We have noted that ^{23}O is identified as a 1n- halo, however, the half-life of it is found to be much larger than that of ^{20}O and other oxygen isotopes.

For the emission of $^{19\text{-}25}$F from the selected super heavy nuclei, the lowest decay half-life is obtained for ^{23}F. For the 1-n halo nucleus, ^{24}F, the decay half-life is found to be much larger than other florin isotopes. In the plots corresponding to the emission of $^{21\text{-}28}$Ne, we can see that there is a peak at parent neutron number 184. Therefore, the parents are stable against the decay of $^{21\text{-}28}$Ne at this neutron number. The minimum half-life of decay is obtained for the decay of ^{26}Ne from all the parent nuclei considered here.

Further, we have studied the effect of quadrupole and hexadecapole deformation of parent, daughter and cluster nuclei by calculating the decay half-life using the Coulomb and Proximity potential Model for Deformed Nuclei. It is found that the decay half-life of decreases when the deformations are introduced in the calculation (Fig.2).

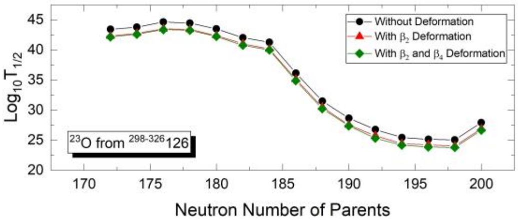

Fig.2: Effect of quadrupole and hexadecapole deformation of the decay half-life for the decay of ^{23}O from $^{298\text{-}326}$126

The quadrupole deformation plays a crucial role and the half-life of decay is largely determined by the deformation of the emitted cluster. Among the selected cluster family, ^{15}N, ^{20}O and ^{23}F has shown lowest half-life of decays corresponding to the formation of daughter nuclei with neutron number as a magic number 184. Therefore, it is evident that the neutron shell closure has a dominant role in providing the stability to the nucleus.

References

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