Possibility for the existence of 2n halo isotopes via cluster decay of nuclei in super heavy region

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Introduction

Neutron and proton 'halo' became an interesting topic for the nuclear physicist since from its discovery by Tanihata et. al. in 1985 [1]. A halo is a nuclear state in which one or two valance nucleons, are decoupled from the tightly bound core and the nucleon-density distribution of these weakly bound nuclei shows an extremely long tail. Halo is a consequence of quantum mechanical tunneling effect and the nucleon remains most of the time beyond the interaction potential of the nucleus. This occurs in nuclei near the dripline where the separation energy of last one or two nucleon is extremely small, (< 1 MeV). A neutron halo is known as 1n- halo if the 1n separation energy is lowest or 2n- halo if the 2n separation energy is the lowest.

The neutron halo was first observed in weakly bound ^{11}Li nucleus and their existence was confirmed in many nuclei such as ^{6}He, ^{9}Be, ^{11}Be, ^{14}Be, ^{14}C, ^{19}C etc. The first neutron halo produced in the laboratory was ^{6}He from a ^{9}Be target. Other predicted neutron halo nuclei include ^{6}He, ^{8}He, ^{12}Be, ^{17}B, ^{19}B, ^{17}C, ^{22}C, ^{22}N, ^{23}O, ^{24}F, ^{26}F, ^{27}F, ^{29}F, ^{29}Ne etc. [2].

In the present work, we made an attempt to study the possibility for the existence of 2n- halo isotopes through the decay of elements in the Superheavy region. We have calculated 2n-separation energies S(2n) of various isotopes of $Z = 2-30$ elements. The calculated 2n-separation energies of possible 2n- halo nuclei are given in table 1. Even though the 2n-separation energy of ^{8}He, ^{12}Be, ^{14}Be, ^{17}B and ^{29}F are greater than 1MeV, they are considered as candidates for 2n- halo nuclei by potential energy consideration [3].

For our study, we considered the decay of the above nuclei through cluster radioactivity from the super heavy elements $^{270\text{-}316}$116, $^{272\text{-}318}$118 and $^{278\text{-}320}$120 by using the Coulomb and Proximity Potential Modal (CPPM).

Nucleus	S(2n) MeV	Configuration
^{6}He	0.9754	2n + ^{4}He
^{8}He	2.1367	2n + ^{6}He
^{11}Li	0.3692	2n + ^{9}Li
^{12}Be	3.6723	2n + ^{10}Be
^{14}Be	1.2704	2n + ^{12}Be
^{17}B	1.3806	2n + ^{15}B
^{19}B	0.0926	2n + ^{17}B
^{22}C	0.0326	2n + ^{20}C
^{27}F	2.0226	2n + ^{25}F
^{29}F	1.4426	2n + ^{29}F
^{34}Ne	0.3026	2n + ^{32}Ne
^{37}Na	0.8426	2n + ^{35}Na

Table 1. 2n separation energies of various neutron halo nuclei.

The Coulomb and Proximity Potential Model

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

$$V = \frac{Z_1 Z_2 e^2}{r} + V_p(z) + \frac{\hbar^2 l(l+1)}{2\mu r^2} \text{ ; for } Z > 0 \quad (1)$$

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.

Results, Discussion and Conclusion

Cluster radioactivity is energetically possible only when the Q-value of the reaction is greater than zero. The Q-values of the reactions are computed using the experimental binding energy data of Audi and Wapstra [4] and the tables of KTUY [5]. Among the selected 2n-halo nuclei, the calculated Q- value is positive only for ^{12}Be, ^{27}F, ^{29}F, ^{34}Ne and ^{37}Na for the decay from the Superheavy elements considered. Hence the decay of other 2n- nuclei given in table 1 are energetically forbidden in super heavy region except from a very few nuclei at the higher mass end. We have computed the half-life of decay of these 2n- halo nuclei from $^{270\text{-}316}$116, $^{272\text{-}318}$118 and $^{278\text{-}320}$120 in super heavy region by using the CPPM.

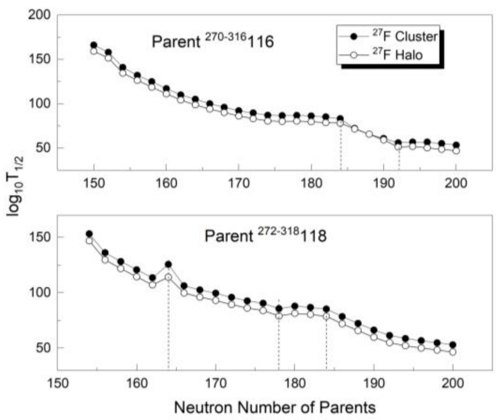

Fig: 1 Comparison of computed half-life for the decay of ^{27}F from $^{270\text{-}316}$116 and $^{272\text{-}318}$118; as a cluster and as a halo nucleus.

Since the halo is a highly deformed nuclear state, we have made a comparison of computed half -life by considering them as a spherical cluster and as a deformed nucleus of rms radius given in terms of quadrupole deformation β_2 as [6];

$$R = R_{sph}\left[1+0.3981\beta_2^2\right]^{1/2} \quad (4)$$

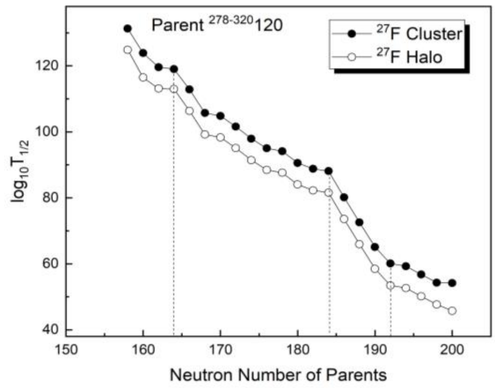

Fig: 2 Comparison of computed half-life for the decay of ^{27}F from $^{278\text{-}320}$120 as a cluster and as a halo nucleus

It is observed that the computed half-life of decay is considerably larger than the experimental limit. This is due to the fact that we have considered heavy 2n- halo nuclei and it is a common observation that the half-life of decay increases with mass number of halo nucleus. Also, it has been observed that half-life of decay is decreased considerably when the rms radius of the of the halo nuclei is considered. Some of the results are given in figures 1 and 2. From the figures, we can see that there is a peak at parent neutron number 164 and 184; and a dip at parent neutron number 178 and 192. A peak indicates the shell closure of the parent and a dip indicates the shell closure of the daughter. From the calculations it is clear that the lowest half-life of decay is obtained for ^{27}F and for other 2n- nuclei, it is much higher than the experimental limit. Therefore, our calculations did not show any significant probability for the emission of 2n-halo nuclei from elements in the super heavy region. However, it reveals the neutron magicity at 164 and 184.

References

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