Studies on probable chances of decay of superheavy element $^{304}120$

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Introduction

Theoretical studies on superheavy nuclei (SHN) have become a prime concern in recent years so that we can develop stable nuclei in the superheavy region and have a better understanding of the nuclear structure. SHN up to Z=118 has been experimentally synthesized so far using the cold and hot fusion evaporation technique and attempt to study Z=120 have been reported. Superheavy element $^{304}120$ is an isotope of great interest among researchers since it has magic number of proton (Z=120) and neutron (N =184).

In the present work, we aim to study the possibilities of SHN $^{304}120$ to emit alpha and heavier cluster using the Modified Generalized Liquid drop model (MGLDM) [1] with Q value dependent pre-formation factor [2] and also we calculate its decay modes by comparing alpha decay half-lives with spontaneous fission half-lives computed using shell effect and mass inertia dependent formula [3, 4].

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Theory

In MGLDM, for a deformed nucleus, the macroscopic energy is defined as,

$$E = E_V + E_S + E_C + E_R + E_P \qquad (1)$$

Here the terms E_V, E_S, E_C, E_R and E_P represents the volume, surface, Coulomb, rotational and nuclear proximity energy terms respectively.

The barrier penetrability P is calculated with the action integral

$$P = \exp\left\{ -\frac{2}{\hbar} \int_{R_{in}}^{R_{out}} \sqrt{2B(r)[E(r) - E(sphere)]}\,dr \right\}$$

Where $R_{in} = R_1 + R_2, B(r) = \mu$, the reduced mass and $R_{out} = e^2 Z_1 Z_2 / Q$. R_1, R_2 are the radius of the daughter nuclei and emitted cluster respectively, Q the released energy.

The partial half-life is related to the decay constant λ by

$$T_{1/2} = \left(\frac{\ln 2}{\lambda} \right) = \left(\frac{\ln 2}{\nu P_C P} \right) \qquad (2)$$

The assault frequency ν has been taken as 10^{20} s^{-1} and the pre-formation factor is given as

$$P_C = 10^{aQ + bQ^2 + C} \qquad (3)$$

With a = -0.25736, b = 6.37291 x 10^{-4}, c = 3.35106 and Q is the Q value of the reaction.

Results and discussion

We have calculated all possible cluster daughter combination possible in the decay of $^{304}120$ using the concept of cold valley reaction plot. Half-lives and branching ratio of all possible fragment combinations of SHN $^{304}120$ are calculated. Half-lives are computed using MGLDM with Q value dependent pre-formation factor. We considered only those splitting of $^{304}120$ which are within the experimental half-life limit (less than 10^{30} s) and branching ratio limit (down to 10^{-19}). Among all possible cluster emission, ^{121}Cd with ^{183}Hf daughter nuclei is found to be the most probable heavy cluster decay of $^{304}120$ with half-lives comparable with alpha decay half-lives. Half-lives of some important splitting of $^{304}120$ are shown in table 1. Also in all possible fragment combinations, ^{133}Te with ^{171}Er daughter nuclei, ^{135}I with ^{169}Ho daughter nuclei and ^{138}Xe cluster with ^{166}Dy daughter nuclei are the most favorable heavy cluster reaction possible, with minimum half-life. These heavy clusters have neutron number N= 82 or near to it, which is a magic number, thereby proving the role of neutron shell closure in heavy cluster decay.

A graph with cluster size along X axis and logarithm of half-lives using MGLDM with Q dependent preformation factor along Y axis, of splitting of ^{304}120 is plotted in figure 1.

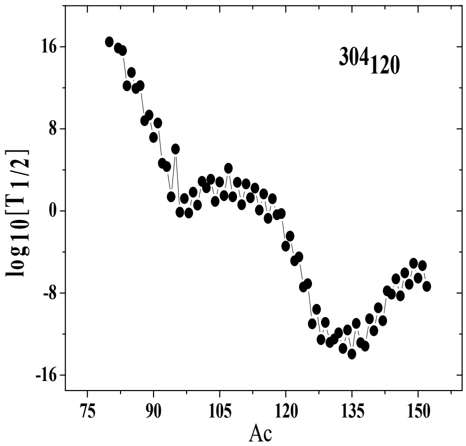

Figure 1. Graph connecting cluster size vs. logarithm of half-life of splitting of ^{304}120.

Table 1: Splitting of ^{304}120 whose half-lives are comparable with alpha decay half-lives and those with minimum half-life are given.

Daughter Nuclei	Probable Cluster	Q Value (MeV)	$T_{1/2}$ (s)
^{300}Og	^{4}He	11.52	0.006648
^{121}Cd	^{183}Hf	344.62	0.003418
^{133}Te	^{171}Er	360.93	3.86E-14
^{135}I	^{169}Ho	362.85	1.13E-14
^{138}Xe	^{166}Dy	362.83	6.50E-14

We also calculated the decay modes of ^{304}120 by comparing alpha decay half-life with spontaneous fission half-lives and are listed in table 2. Alpha decay half-lives are calculated using the MGLDM and Spontaneous fission half-lives are calculated using the shell effect and mass inertia dependent equation [3, 4] and is,

$$\log_{10}[T_{1/2}(yr)] = c_1 + c_2\left(\frac{z^2}{(1-kI^2)A}\right) + c_3\left(\frac{z^2}{(1-kI2)A}\right)^2 + c_4 E_{sh} + c_5 I_{rigid} + h_i$$

The rigid body mass inertia of the nucleus [5, 6] is given as

$$I_{rigid} = B_{rigid}[1+0.31\beta_2 + 0.44\beta_2^2 + ...] \quad (4)$$

With the mass parameter,

$$B_{rigid} = \frac{2}{5}MR^2 = 0.0138\, A^{5/3}(\hbar^2 / MeV) \quad (5)$$

The value of constants are c_1 = 1208.763104, c_2 = -49.26439288, c_3 = 0.486222575, c_4 = 3.557962857, c_5 = 0.04292571494, k = 2.6 and hi, is blocking effect given in Ref. [3, 4].

From table it is clear that for first 4 decays, alpha decay half-life is less compared to spontaneous fission half-life and in the fifth case, spontaneous fission half-life is less. Thus without any doubt, we can say that for superheavy element ^{304}120, decays by 4 alpha chains followed by spontaneous fission.

Table 2: Comparison of alpha decay half-lives with spontaneous fission half-lives and the decay modes of ^{304}120.

Parent Nuclei	Q_α (MeV)	T_{SF} (s)	T_α (s)	Mode of decay
^{304}120	11.52	48.85028	0.00665	α
^{300}Og	11.04	7.56E+03	0.02792	α
^{296}Lv	10.51	2.13E+06	0.17724	α
^{292}Fl	8.38	7.99E+06	2.83E+05	α
^{288}Cn	7.95	2.19537	2.20E+04	SF

References

[1] K. P. Santhosh, C. Nithya, H. Hassanabadi and Dashty T. Akrawy, Phys. Rev. C 98, (2018): 024625.
[2] K. P. Santhosh and Tinu Ann Jose, Phys. Rev. C 99, (2019): 064604.
[3] K. P. Santhosh, Tinu Ann Jose and N. K. Deepak, Phys. Rev. C 103, (2021): 064612
[4] K. P. Santhosh, C. Nithya and Tinu Ann Jose, Phys. Rev. C 104, (2021): 024617.
[5] A. Bohr and B. R. Mottelson, Dan. Mat. Fys. Medd. 30, (1955): 1.
[6] J. M. Allmond and J. L. Wood, Phys. Lett. B 767, (2017): 226.