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Competition between alpha and heavy cluster decay in superheavy element ^{296}Og

Tinu Ann Jose & K P Santhosh*
School of Pure and Applied Physics, Kannur University, Swami Anandatheertha Campus, Payyanur 670 327, India

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Systematic study of superheavy nuclei ^{296}Og and its possibilities to emit alpha particle and heavier clusters are studied using Modified Generalized Liquid Drop Model (MGLDM) with Q value dependent preformation factor. Half-lives and branching ratio of all possible cluster emission of ^{296}Og is checked and only those cluster which are within the experimental half-lives limit (less than 10^{30}s) and branching ratio limit (down to 10^{-19}) are considered. Among this, ^{88}Kr is found to be the most probable heavy cluster, leading to doubly magic ^{208}Pb daughter nuclei, with half-lives comparable with alpha decay half-lives. Thus the role of doubly magic daughter nuclei in cluster decay is highlighted here. Again the decay modes of ^{296}Og are also studied by comparing alpha decay half-lives using MGLDM with spontaneous fission half-lives proposed by Bao *et al.*, and from this, it is found that for superheavy element ^{296}Og, decays by 3 alpha chains followed by spontaneous fission. We hope that this study would help when this emission is experimentally detected in near future.

Keywords: Alpha decay, Spontaneous fission, Superheavy element

1 Introduction

Studies on Superheavy nuclei (SHN) have become one of the hot and popular research topic in the field of nuclear physics. Several SHN up to Z = 118 have been experimentally synthesized so far using both cold fusion reaction[1] and hot fusion reaction[2]. One of the reliable ways to understand the properties of newly produced SHN is to check its decay modes. Alpha decay and spontaneous fission are the main decay modes of SHN. Various theories are proposed by researchers to explain alpha decay of heavy and SHN[3-8]. In addition to alpha decay, several theoretical studies are done to check the possibilities of heavy cluster emission from SHN[9-12]. Royer[13-16] proposed Generalized Liquid Drop Model (GLDM) by adding quasi-molecular shape and nuclear proximity potential to conventional Liquid Drop Model. Our group[17] modified GLDM by including proximity potential proposed by Blocki*et al.*,[18] and is termed as Modified Generalized Liquid Drop Model (MGLDM)

In our present work, we use MGLDM with Q value dependent preformation[19] to calculate half-lives of all splitting of ^{296}Og.

2 Modified Generalized Liquid Drop Model (MGLDM)

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

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

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

For the pre-scission region the volume, surface and Coulomb energies in MeV are given by,

$$E_V = -15.494(1-1.8I^2)A , \qquad \dots (2)$$

$$E_S = 17.9439(1-2.6I^2)A^{2/3}(S/4\pi R_0^2) , \qquad \dots (3)$$

$$E_C = 0.6e^2(Z^2/R_0)\times 0.5\int (V(\theta)/V_0)(R(\theta)/R_0)^3 \sin\theta \, d\theta \qquad \dots (4)$$

Here I is the relative neutron excess and S the surface of the deformed nucleus, $V(\theta)$ is the electrostatic potential at the surface and V_0 the surface potential of the sphere.

For the post-scission region,

$$E_V = -15.494[(1-1.8I_1^2)A_1 + (1-1.8I_2^2)A_2] , \qquad \dots (5)$$

$$E_S = 17.9439[(1-2.6I_1^2)A_1^{2/3} + (1-2.6I_2^2)A_2^{2/3}] , \qquad \dots (6)$$

$$E_C = \frac{0.6e^2Z_1^2}{R_1} + \frac{0.6e^2Z_2^2}{R_2} + \frac{e^2Z_1Z_2}{r} . \qquad \dots (7)$$

Here A_i, Z_i, R_i and I_i are the masses, charges, radii and relative neutron excess of the fragments, r is the distance between the centers of the fragments.

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*Corresponding author (E-mail: drkpsanthosh@gmail.com)

The nuclear proximity potential E_P is given by Blocki*et al.*,[18] as:

$$E_p(z) = 4\pi\gamma b\left[\frac{C_1C_2}{(C_1+C_2)}\right]\Phi\left(\frac{z}{b}\right), \qquad \dots (8)$$

With the nuclear surface tension coefficient:

$$\gamma = 0.9517\ [1 - 1.7826\ (N - Z)^2 / A^2]\ \text{MeV/fm}^2, \qquad \dots (9)$$

Where N, Z and A represent neutron, proton and mass number of parent nucleus respectively, Φ represents the universal proximity potential[20] given as:

$$\Phi(\varepsilon) = -4.41e^{-\varepsilon/0.7176}\text{, for } \varepsilon > 1.9475, \qquad \dots (10)$$

$$\Phi(\varepsilon) = -1.7817 + 0.9270\ \varepsilon + 0.01696\ \varepsilon^2 - 0.05148\ \varepsilon^3$$
$$\text{for } 0 \le \varepsilon \le 1.9475, \qquad \dots (11)$$

with $\varepsilon = z/b$, where the width (diffuseness) of the nuclear surface $b \approx 1$ fm and Süsmann central radii C_i of fragments related to sharp radii R_i as:

$$C_i = R_i - \left(\frac{b^2}{R_i}\right). \qquad \dots (12)$$

For R_i we use semi empirical formula in terms of mass number A_i as[20]:

$$R_i = 1.28A_i^{1/3} - 0.76 + 0.8A_i^{-1/3} \qquad \dots (13)$$

The barrier penetrability P is calculated with the action integral:

$$\text{P} = \exp\left\{-\frac{2}{\hbar}\int_{R_{in}}^{R_{out}}\sqrt{2B(r)[E(r) - E(sphere)]}dr\right\}, \qquad \dots (14)$$

Where $R_{in} = R_1 + R_2, B(r) = \mu$ and $R_{out} = e^2Z_1Z_2/Q$. R_1, R_2 are the radius of the daughter nuclei and emitted cluster respectively, and μ the reduced mass and Q the released energy.

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

$$T_{1/2} = \left(\frac{\ln 2}{\lambda}\right) = \left(\frac{\ln 2}{\nu P_C P}\right). \qquad \dots (15)$$

The assault frequency ν has been taken as 10^{20} s^{-1} and the preformation factor[19] is given as:

$$P_C = 10^{aQ + bQ^2 + C}, \qquad \dots (16)$$

With a= -0.25736, b=6.37291 x 10^{-4}, c=3.35106 and Q is the Q value or the energy released in a radioactive nuclear reaction.

3 Results and Discussion

Half-lives of all possible splitting of ^{296}Og is studied using MGLDM with Q value dependent preformation factor. Among all splitting, we considered only those splitting of ^{296}Og which are below experimental half-life upper limit and within branching ratio limit. Graphical representation of logarithm of half-life of all splitting of ^{296}Og versus mass number of cluster emitted is plotted and is shown in Fig. 1. Straight line drawn in the figure corresponds to alpha decay half-life of ^{296}Og. From the graph, one can clearly understand the most probable cluster that may be emitted from ^{296}Og with half-life comparable with that of alpha decay half-life.

Alpha decay half-life of ^{296}Og is calculated and is found to be 97.2808 s. Among all splitting within experimental limits, ^{88}Kr with ^{208}Pb daughter nuclei and ^{116}Pd with ^{180}Hf daughter nuclei are considered as most probable decay of SHN ^{296}Og with half-lives comparable with alpha decay half-life. Also, when we examine all the splitting, it is evident that ^{138}Xe with ^{160}Gd daughter nuclei is the most stable heavy cluster reaction possible with minimum half-life among all decay. ^{208}Pb daughter nuclei considered above has Z =82 and ^{138}Xe has N= 82. Thus in above considered cluster reaction, either cluster emitted or daughter nuclei has neutron number N= 82 or atomic number Z=82, which is a magic number, thereby proving the role of stability of shell closure in cluster decay.

We also calculated the decay modes of ^{296}Og by comparing alpha decay half-life with spontaneous fission half-life and are listed in Table 1. Alpha decay

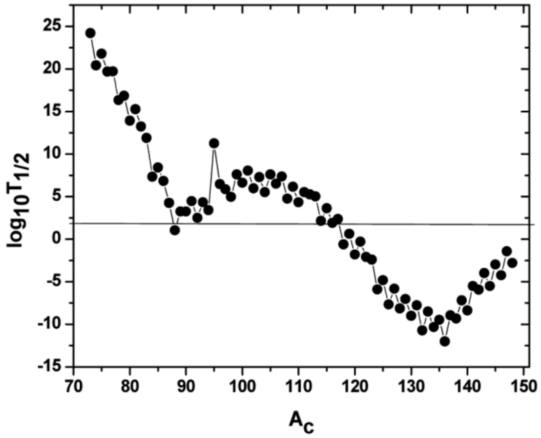

Fig. 1 — Graphical representation of logarithm of half-life versus mass number of cluster for the splitting of ^{296}Og.

Table 1 — Decay modes of ^{296}Og by comparing alpha decay half-lives with spontaneous fission half-lives predicted by the framework proposed by Bao *et al.*,[21].

Parent Nuclei	Q_α (MeV)	T_{SF} (s)	T_α (s)	Mode of decay
^{296}Og	9.805	311581.1245	97.2808	α
^{292}Lv	10.775	220330.2358	0.0391	α
^{288}Fl	10.065	898.0416	0.8386	α
^{284}Cn	9.605	0.0051	4.3119	SF

half-life are calculated using our method of MGLDM whereas spontaneous fission half-life are calculated using equation proposed by Bao *et al.*,[21] and is given as:

$$\log_{10}[T_{1/2}(yr)] = c_1 + c_2\left(\frac{Z^2}{(1-kI^2)A}\right) + c_3\left(\frac{Z^2}{(1-kI^2)A}\right)^2 + c_4 E_{sh} + h_i \cdots (17)$$

With c_1 = 1174.35341, c_2 = -47.666855, c_3 = 0.471307, c_4 = 3.378848, k = 2.6 and h_i is blocking effect given in Ref.[21].

From Table 1, when we compare both alpha decay half-life and spontaneous fission half- life, it is evident that the first three sequential alpha decay half-life are less in comparison with spontaneous fission half-life. And for the next decay, SF half-life has minimum value. Thus we can conclude that SHN ^{296}Og decays by 3 alpha chain followed by spontaneous fission.

4 Conclusions

Theoretical study on the SHN ^{296}Og and the probabilities of this element to emit alpha and other heavy cluster is studied using MGLDM with Q value dependent preformation factor. ^{88}Kr with ^{208}Pb daughter nuclei and ^{116}Pd with ^{180}Hf daughter nuclei are the considered as most probable decay of SHN ^{296}Og. Also, the role of magic number in stability is also explained. Finally, decay modes of ^{296}Og are predicted. We hope that our present predictions would help for future studies in this field.

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