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Deformation Consequences in Super Heavy Elements

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***Abstract*— The Search for new super heavy elements is at present one of the most exciting adventures in the field of nuclear physics. Majority of super heavy elements are identified through alpha decay chain since many nuclei in the super heavy region are expected to decay mainly by alpha emission. Alpha decay is a unique tool to study the properties of a nucleus which assists for the experimental studies of super heavy nuclei, as it makes their identification easier. In order to investigate such alpha decay half-life times of super heavy nuclei, Cubic plus Yukawa plus Exponential (CYE) model in the Trans-Actinide region ranging from Z = 104 to 121. This model uses a cubic potential in the over-lapping region connected by a Yukawa plus Exponential potential in the post – scission region. Apart from using this potential CYE model has more virtues, for instance inclusion of zero point vibration energy. Such a model is enhanced further by incorporating the consequence of deformation of the decay parent and the daughter nucleus. This can cause longevity and stability of super heavy nuclei. The expected long lived super heavy nuclei provide the physicists to have an extensive study about the properties of super heavy elements. In this work by using CYE model the alpha decay half-lives of Super heavy nucleus including the effect of nuclear deformation is analyzed.

Keywords*—*Alphadecay ,Deformation, Half–lives, Super heavy elements

I. INTRODUCTION

Super heavy elements have all been created during the latter half of the 20th century and are continually being created during the 21st century. The technology advancement leads to the acceptance of the actinide series (i.e.) the existence of a Trans-Actinide series ranging from elements 104 to 121 and Super Actinide series ranging from elements 122 to 153. Currently researches are going on to detect the stability of super heavy element with Z ≥120. In this work, the area of interest lies in the Trans-Actinide region and their half-lives are calculated for the atomic range Z = 104 to 121. First we have calculated the half-life of super heavy elements in two sphere approximation without taking into account the effect of deformation [1]. Since all the heaviest element found recently are believed to be well deformed, the deformation of the parent nucleus and the fragments are incorporated in the half-life time calculation of super heavy elements. Here the effect of ground state deformation are considered in the parent nucleus whereas the deformation effects have been included both in the coulomb energy and the surface energy due to Yukawa plus Exponential (Y+E) potential treating the daughter nucleus as spheroid and the emitted fragments as spherical.

Rest of the paper is organized as follows, Section I contains the introduction about super heavy elements and concisely explains about the half life time calculation, Section II explains about the realistic CYE model, Section III and IV describes the calculation of coulomb potential in the post-scission and pre-scission region, Section V contains the results and discussion, Section VI concludes research work with future guidelines.

II. REALISTIC CUBIC PLUS YUKAWA PLUS EXPONENTIAL POTENTIAL MODEL

To study the decay properties, a realistic model [2] Cubic plus Yukawa plus Exponential potential (CYE) model is used. The zero-point vibration energy is explicitly included without violating the conservation of energy and the inertial mass coefficient dependent on the center of mass distance. It has a cubic potential for the overlapping region which is smoothly connected by a Yukawa plus Exponential potential for the region after separation. Then the potential as a function of r for the post-scission region is given by,

$$V(r) = \frac{Z_1 Z_2 e^2}{r} + V_n(r) - Q, \;\; r \geq r_t$$

(1)

The half-life time of the system is calculated using [3]

$$T = \frac{1.433 \; x \; 10^{-21} \; (1+expK)}{E_v} \qquad (2)$$

where

$$k = \frac{2}{\hbar}\left\{\int_{r_a}^{r_t} [2B_r(r)V(r)]^{1/2} \; dr + \int_{r_t}^{r_b} [2B_r\,(r)V(r)]^{1/2}\right\} \mathrm{dr} \qquad (3)$$

here r_a and r_b being the two appropriate zeros of the integrand.

III. POTENTIAL FOR THE POST-SCISSION REGION

For exotic decay studies that essentially consists of a cubic potential in the overlapping region which is smoothly connected by a Yukawa plus Exponential potential in the region after separation. If the daughter nucleus has a deformation, say quadruple deformation only, while the emitted nucleus is spherical and if the Q-value of the reaction is taken as the origin, then the potential for the post -scission region as a function of the center of mass distance r of the fragments is given by

$$V(r) = V_c(r) + V_n(r) - V_d(r) - Q, r \geq r_t \tag{4}$$

Here, $V_c(r)$ is the coulomb potential between a spheroidal daughter and spherical emitted fragment, $V_n(r)$ is the nuclear interaction energy due to finite range effects, $V_d(r)$ is the change in the nuclear interaction energy due to quadruple deformation (β_2) of the daughter nucleus. The coulomb potential between the emitted fragments is taken as the interaction of a spheroidal daughter nucleus and a spherical emitted fragment. An expression for the nuclear interaction energy for the case of a spherical nucleus 1 interacting with a deformed nucleus 2 whose nuclear surface is specified in spherical polar co-ordinates r, θ, and Φ is given by the equation.

$$V_n(r) = D\left[F + \frac{(r-r_{12})}{a}\right]\frac{r_{12}}{r}\, xexp\left[\frac{r_{12}-r}{a}\right]$$

(5)

The Change in the nuclear interaction energy due to the quadrupole deformation β_2 [4] of nucleus 2 is given by

$$V_d = \frac{4R_2^3 C_s A_2 \beta_2}{a r_0^2}\left(\frac{5}{4\pi}\right)^{1/2}$$

(6)

IV. POTENTIAL FOR THE PRE-SCISSION REGION

The shape of the barrier in the overlapping region which connects the ground – state and the contact – point is approximated by a third – order polynomial in r having the form

$$V_{(r)} = -E_v + [V(r_t) + E_v]\left\{S_1\left[\frac{r-r_i}{r_t-r_i}\right]^2 - S2\left[\frac{r-r_i}{r_t-r_i}\right]^3\right\}; r_i \leq r \leq r_t$$

(7)

Where r_i is the distance between the center of mass of two portions of the daughter and the emitted nuclei in the spheroidal parent nucleus and $r_t = a_2 + R_1$. Here, a_2 is the semi-major or minor axis of the spheroidal daughter nucleus depending on the shape. In the calculation of lifetimes, to include the zero-point vibration energy E_v, it is important to keep the conservation energy as preserved. This procedure is to fit the cubic part of the barrier not to zero at $r = r_i$ but to $-E_v$ [5].

$$E_V = \frac{\pi\hbar}{2}\frac{\left[\frac{2Q}{\mu}\right]^{1/2}}{(C_1 + C_2)} \tag{8}$$

Where C_1 and C_2 are the "central" radii of the fragments

$C_i = 1.18\ A_i^{1/3} - 0.48,$ (i = 1, 2)

and μ is the reduced mass of the system

V. RESULTS AND DISCUSSION

In our earlier work [6,7] we have calculated the alpha decay half life time values with deformation for few super heavy elements using CYE model. In this work, we have calculated the alpha decay half life time values of SHE in the Trans – Actinide region including the deformation effects both in parent and daughter nucleus. The Q values for this calculation are taken from the references [8,9,10] and the values for deformation parameters are taken from the reference [11].

***Table1**. Comparison of half-life time values calculated using CYE model (without and with deformations) with the theoretical and available experimental values.*

Parent	**Q(MeV)**	**Log T (s)**			**Ref.**
		CYE Model		***Ref. Values***	
		WoD	***WD***		
${}^{265}_{104}$	7.78	4.77	2.17	5.03	[12]
${}^{268}_{105}$	8.2	3.54	0.98	3.93	[12]
${}^{271}_{106}$	8.54	3.68	0.14	3.056	[13]
${}^{266}_{107}$	9.08	1.36	-1.2	0.1139	[21,22]
${}^{270}_{107}$	8.93	1.78	-0.7	1.7853	[23]
${}^{270}_{108}$	9.3	9.55	0.03	2.02	[12]
${}^{276}_{109}$	9.79	-0.22	-0.1	-0.328	[8]
${}^{274}_{109}$	9.76	-0.1	-0.5	-0.351	[23]
${}^{280}_{111}$	9.81	0.41	0.48	0.3617	[14]
${}^{277}_{112}$	11.62	-3.94	-6.2	-3.161	[24]
${}^{282}_{113}$	10.63	-1.2	-3.4	-1.137	[23]
${}^{285}_{114}$	11	-1.87	-3.7	-1.35	[12]
${}^{293}_{118}$	12.3	-3.77	-5.5	-3.23	[12]
${}^{295}_{119}$	10.94	-0.12	-0.1	-0.77	[8]
${}^{296}_{119}$	10.81	0.22	0.59	-0.42	[8]
${}^{299}_{121}$	11.91	-1.98	-1.7	-2.585	[8]

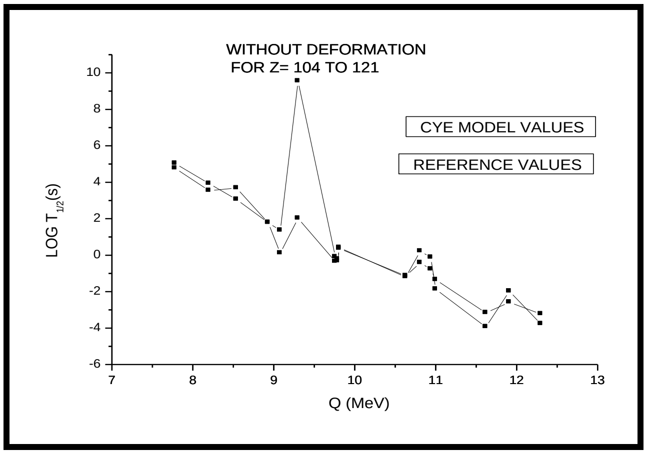
In Table 1, we have calculated and presented the half-life time values without and with deformation effects. The results are compared with the available theoretical and experimental values. The inclusion of deformation effects decreases the half-life time values. In most of the cases the calculated half-life time values approaches the experimental values due to the inclusion of deformation effects.

Table 2. Comparison of half-life time values with different Q values calculated using CYE model (without and with deformations) with the theoretical and available experimental values.

Parent	Q (MeV)	Log T (s)			Ref.
		CYE Model		***Ref. Values***	
		WoD	***WD***		
$^{272}_{107}$	9.02	1.45	2.5	2.057	[13]
	9.09	1.22	1.26	0.799	[14]
$^{275}_{109}$	10.42	-1.97	-1.85	-2.2757	[14]
	10.33	-1.73	-4.06	-2.0132	[15,16]
$^{279}_{110}$	9.7	0.37	0.74	-0.6989	[13]
	9.6	2.34	-1.95	14.3	[13]
$^{279}_{111}$	10.37	-1.17	-3.54	-0.7696	[15,16]
	10.36	-1.15	-1.03	-1.0457	[14]
$^{283}_{113}$	10.12	0.2	-2.08	-1	[15,16]
	10.17	0.05	0.09	-1.2596	[14]
$^{284}_{113}$	10	0.53	-1.56	-3.188	[15,16]
	10.09	0.27	0.21	-5086	[14]
$^{287}_{114}$	10.02	0.8	-1.18	-3.188	[13]
	10.04	0.74	-1.24	0.0414	[17]
$^{286}_{114}$	10.2	0.29	-1.67	-0.796	[17]
	10.19	0.32	-1.64	-0.886	[13]
	10.03	0.79	-1.2	-0.5376	[24]
$^{288}_{114}$	9.95	0.99	-1	-0.0969	[17,18]
	9.94	1.02	-0.97	-0.2006	[17]
$^{289}_{114}$	9.81	1.4	-0.61	0.2304	[17,18]
	9.84	1.36	-0.7	0.278	[19]
$^{288}_{115}$	10.46	-0.12	-2.02	-1.0605	[15,16]
	10.55	-0.37	-0.15	-1.2441	[14]
$^{287}_{115}$	10.59	-0.46	-2.31	-1.495	[15,16]
	10.65	-0.62	-0.43	-1.7447	[14]
	10.66	-0.38	-2.12	-1.7447	[17]
$^{292}_{116}$	10.87	-0.95	-2.67	-1.4685	[20]

$\boldsymbol{\beta}_{2p}$, $\boldsymbol{\beta}_{4p}$, $\boldsymbol{\beta}_{2d}$ are the Quadrapole deformations of the parent and the daughter nucleus.

In Table 2, the results obtained due to the calculation of half-life time values using different available Q values for the same decay mode and the values are compared with reference values. This calculation reveals that not only deformation but also even a small variation in Q value varies the half life time values.



\Fig. 1 shows the comparison of half-life time values of Trans-Actinide elements without deformation using CYE model with the reference values.

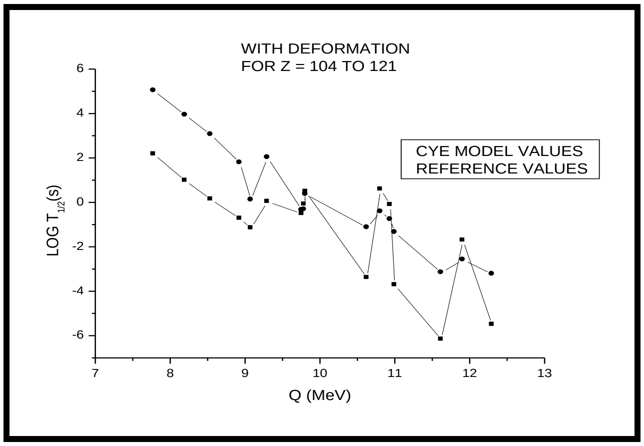
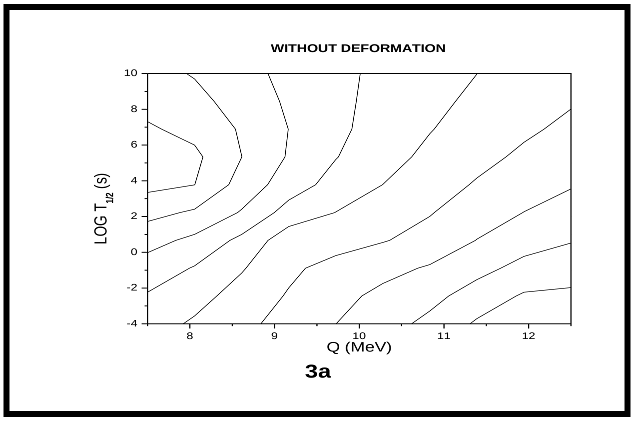


Fig. 2 shows the comparison of half-life time values of Trans-Actinide elements with deformation using CYE model with the reference values.



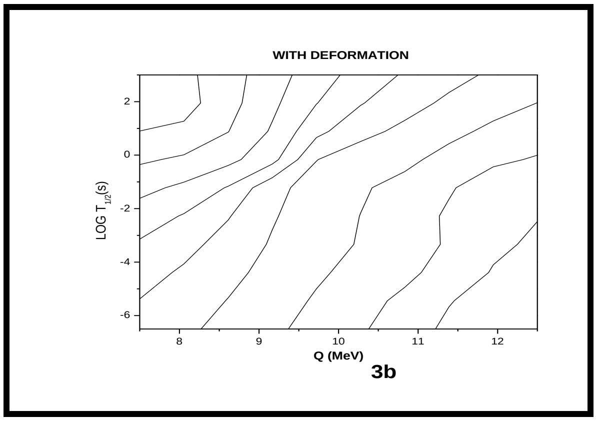


Fig. 3a & 3b predicts the contour plot of half-life time values of Trans-Actinide elements using CYE model without and with deformation effects.

The contours plotted in Fig. 3a & 3b are drawn to study the changes in half-life time values for super heavy element without and with incorporating the consequence of deformation. The closed contours represent the region of instability. The area of contours in Fig. 3b is much reduced and tends to become straight lines towards the boundary when compared to contour plot of half-life time values in Fig. 3a. This implies the fact that the stability of the daughter nucleus increases due to the consequence of deformation in the parent nucleus.

VI. CONCLUSION AND FUTURE SCOPE

In this work, the deformation effects on the life time calculations are studied. The effects of ground-state deformations are considered in the parent nucleus whereas the deformation effects have been included both in the coulomb energy and the surface energy due to Yukawa plus exponential potential treating the daughter/emitter nucleus as spheroid/sphere. Thus by considering the deformation effects the half-lives of Trans - Actinide elements in the range Z = 104 to 121 are calculated using CYE model and compared with the available theoretical and experimental values. While applying deformation to both the parent and the daughter nuclei, it is seen that the inclusion of deformation effects lowers the half life time values. As inferred in Table 2, a small variation in Q values also varies the half life time values. That is both the deformation effects and also Q values play a vital role in the study of decay properties of super heavy elements. Finally, we conclude that the consequence of deformation leads to feasibility of stability in emitted nucleus. The stabilization in the Trans-Actinide region due to deformation enables us to extract basic information on the structure of the elements which in turn will provide a new guide for future experiments.

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