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Effective Liquid Drop Model Description For Alpha and Cluster Decay of Nuclei in the Super-Heavy Mass Region

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ABSTRACT *Decay half-lives for alpha and cluster emission from parent nuclei having atomic numbers 111,112,113,114,115,116 and 117 in the super heavy mass region are investigated using the effective liquid drop model. Comparison is made with a microscopic model. The deformation effect of parent is also considered.*

KEYWORDS : Super-heavy nuclei, alpha decay, cluster decay

I. Introduction

The spontaneous emission of fragments heavier than α-particles but lighter than the lightest fission fragment is termed as cluster radioactivity. This decay mode was predicted by Sandulescu, Poenaru and Greiner in 1980[1]. Later in 1984, Rose and Jones[2] observed ^{14}C radioactivity from ^{223}Ra. Many theoretical models have been used to explain the experimental results of decay half-lives of different nuclei[3,4,5] . The interest in the newly synthesized nuclides have prompted many investigators to carry out theoretical studies on the decay prospects of many of these nuclides using different models[6,7,8].

In this work, we calculated the half-life for the emission of α, ^{14}C and ^{16}O from $^{279}111$,$^{280}112$, $^{279}113$,$^{288}114$, $^{287}115$,$^{292}116$ and $^{291}117$.The effect of the deformation of parent nuclei is also considered.

II. The Model

We have used the effective liquid drop model for the evaluation of the barrier penetrability. Here the multi-dimensional problem is reduced to one dimensional one by assuming geometrical constraint necessary to preserve the adopted shape. In the whole process, the volume of the system is considered as constant. Total potential is given by:

$$V = V_c + V_s + V_l - V_o \qquad \text{(i)}$$

The Coulomb potential Vc as suggested by Gaudin[9] is given by:

$V_c = 8/9[\pi a^5 \in (x_1,x_2)]\rho_c$ (ii)

where, ρ_c is the initial charge density and $\in(x_1,x_2)$ is a

function of the angular variables x_1 and x_2.

The surface potential

$V_s = \sigma_{eff}(S_1+S_2)$ (iii)

where, s_1 and s_2 are the surface areas of each of spherical fragments.

$Si = \pi Ri (Ri + \delta i)$ (iv)

V_0 is the reference potential corresponding to the sum of potential self-energies of each fragment in the asymptote region and V_l is the centrifugal potential. The barrier penetration probability is given by:

$P = \exp[-2/\hbar \int \xi(2\mu eff (V-Q))1/2 \, d\xi$ has to be given as $P = \exp[-2/\hbar \int (2\mu eff(V-Q))1/2 \, d\xi$ (v)

The limits of integration are taken from ε_0 to ε

where, $\varepsilon_0 = R_p - R_1$,R_1 is the final radius of the lighter fragment.

The effective mass;

$\mu_{eff} = M1M2/M1+M2$ (vi)

The decay rate

$\lambda = \lambda_0 P$ (vii)

λ_0 being the assault frequency and is taken as 10^{22}/second. Then half-life is given by:

$T\,½ = \ln 2/\lambda$ (viii)

III. Results and Discussion

We calculated the half life for the emission of alpha, carbon and oxygen from different parents in the super heavy region. Alpha decay is a dominant decay mode in most of the newly synthesized super heavy nuclei. There are several theoretical studies on α decay of super heavy nuclei[10,11,12,13,14,15,16,17,18,19,20]

The emission of clusters heavier than alpha particle from super heavy nuclei is of high significance. Since the final residue of cold reactions is the alpha or cluster decay product of the compound nucleus. Several results, both theoretical and experimental have been already reported.[21,22,23,24,]. The deformation effect of parents is also considered in Table1 and Table2.

Table1:Half-life values for various decay modes of odd-even nuclei

Parent	Daughter	Cluster	β_2	β_4	Log T ½(Proximity potential)		LogT1/2 (Effective liquid drop model)
					Without Deformation	With Deformation	Without Deformation
^{279} 111	^{275}109	4He	0.164	0.063	-1.49532	-1.60671	-2.3715
	^{265}105	^{14}C	0.164	0.063	23.756	22.9753	21.4654
	^{263}Lr	^{16}O	0.164	0.063	32.4127	30.8173	26.0435
^{279} 113	^{275} 111	^{4}He	0.164	-0.072	-3.59729	-3.6668	-4.2982
	^{265} 107	^{14}C	0.164	-0.072	20.7933	21.4147	19.3576
	^{263} 105	^{16}O	0.169	-0.072	26.3756	25.1637	20.8052

^{287}115	^{283}113	^{4}He	-0.096	0.027	-0.7323	-0.6637	-1.7246
	^{275}Mt	^{12}C	-0.096	0.027	24.0464	24.8087	19.8870
	^{267}Bh	^{20}O	-0.096	0.027	34.8863	35.6916	30.8872
^{291}117	^{287}115	^{4}He	0.072	-0.031	-1.8245	-1.86778	-2.7386
	^{277}Rs	^{14}C	0.072	-0.031	25.5873	25.2601	22.7030
	^{275}Mt	^{16}O	0.072	-0.031	30.0667	29.4575	23.5949

Table2:Half-life values for various decay modes of even-even nuclei

Parent	Daughter	Cluster	β_2	β_4	Log T ½ (Proximity potential)		LogT1/2 (Effective liquid drop model)
					Without Deformation	With Deformation	Without Deformation
^{280}112	^{276}110	^{4}He	0.08	-0.006	-1.70624	-1.80583	-2.5747
	^{266}Sg	^{14}C	0.08	-0.006	22.5296	21.8386	20.3617
	^{264}Rf	^{16}O	-0.08	-0.006	30.5292	29.1134	24.367
^{288}114	^{284}Cn	^{4}He	0.053	-0.023	0.763588	.725872	-0.3375
	^{274}Hs	^{14}C	0.053	-0.023	26.8495	26.6149	23.9585
^{292}116	^{288}Fl	4_{He}	-0.07	-0.006	-0.6405	-0.5422	-1.6486
	^{278}Df	14_{C}	-0.07	-0.006	27.2571	28.0481	24.1977
	^{276}Hs	16_{O}	-0.07	-0.006	36.6186	35.0207	27.8766

The proximity potential is used for this calculation.Table3 gives the variation of $\mathbf{T_{1/2}}$ for the emission of alpha from parents with Z=111 to Z=115 and N varying from 168 to 176.Variation of $T_{1/2}$ with Z and N of parent is evident and the present calculation is giving comparable results with that of others reported in the same table [25].

Table3:Comparison of half-life values of present model with other models

Parent	Cluster	Half life values				
		Present model	SHF	RMF	FRDM	Expt
^{279}111	^{4}He	$10^{-2.3715}$s	0.56 s	27.53 s	$10^{-2.36}$s	0.175
^{280} 111	^{4}He	$10^{-1.2524}$s	19.59s	557.61 s	$10^{.03}$s	5.1
^{281}111	^{4}He	$10^{0.0008}$s	1.55 x 10^{-10}s	1.64 x 10^{-7}s	$10^{1.9}$s	--
^{282}111	^{4}He	$10^{1.539}$s	6.29 x10^{-10}s	15526.06 s	$10^{4.1}$s	0.74 s
^{282}112	^{4}He	$10^{-0.5755}$s	1.04 x $10^{-12\,s}$	29.46 s	$10^{1.3}$s	--
^{284}112	^{4}He	$10^{1.031}$s	7.15 x 10^{-5} s	0.012s	$10^{3.67}$s	$9.8^{+18}_{-3.8}$s
^{285}112	^{4}He	$10^{1.2477}$s	1.97 x 10^{7}s	5.44 s	$10^{5.09}$s	29 s
^{283} 113	^{4}He	$10^{-2.3586}$s	8.2 ms	21.28 s	$10^{1.66}$s	88.9 ms
^{284}113	^{4}He	$10^{-0.7909}$s	46.84 ms	94.43 s	$10^{3.61}$s	1.36 s
^{285}113	^{4}He	$10^{-0.0475}$s	5.74 x 10^{19}s	203.59 s	$10^{3.86}$s	7.9 s
^{286}113	^{4}He	$10^{0.2635}$s	9.55x10^{33}s	1.27 s	$10^{4.44}$s	28.3s
^{286}114	^{4}He	$10^{-1.0851}$s	4.57 x 10^{8}s	1.26 s	$10^{2.08}$s	$0.13^{+.01}_{-.01}$ s
^{287}114	^{4}He	$10^{-0.5275}$s	1.23 x 10^{5}s	29.91 s	$10^{3.39}$s	3.8s
^{288}114	^{4}He	$10^{-0.0907}$s	5.33 x 10^{9}s	3.67 x 10^{5}s	$10^{4.86}$s	2.6s
^{289}114	^{4}He	$10^{-0.0907}$s	5.33 x 10^{9} s	3.67 x 10^{5} s	$10^{4.86}$s	2.6 s
^{287}115	^{4}He	$10^{-1.7246}$s	1.49 x 10^{12} s	42.8 ms	$10^{.63}$s	32 ms
^{288}115	^{4}He	$10^{-1.3996}$s	318.88 ms	426.6 ms	$10^{1.33}$s	250 ms
^{289}115	^{4}He	$10^{-1.0126}$s	482.31 ms	204.84 ms	$10^{1.26}$s	320 ms
^{290}115	^{4}He	$10^{-0.6377}$s	0.165 s	11050.16 s	$10^{1.9}$s	0.023 s
^{291}115	^{4}He	$10^{-0.4066}$s	87783.45 s	8.45 s	$10^{2.34}$s	--

More extensive calculations using new mass tables are to be carried out to get more conclusive result. However the results indicate that effective liquid drop model could be used confidently for similar estimates. Q values were estimated using Mass tables of Audi and Wapstra[26] .

IV. Conclusion

The present study using effective liquid drop model has shown that it is a reliable theoretical model for such studies. The effect of parent deformation is also evident from the decrease in half-life values as the inclusion of parent deformations. It also opens the possibility of extending these studies to super heavy regions where similar studies have not been attempted.

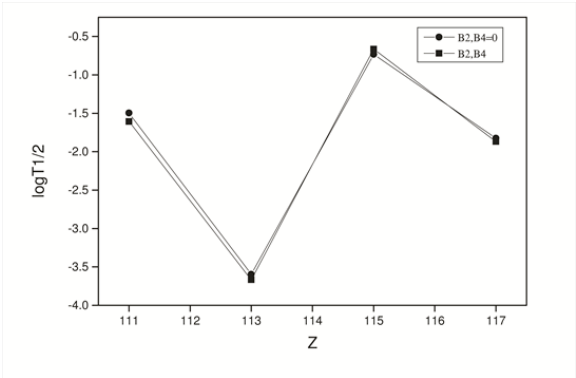

Figure 1. Deformation effect of Parents in α emission for odd Z parents

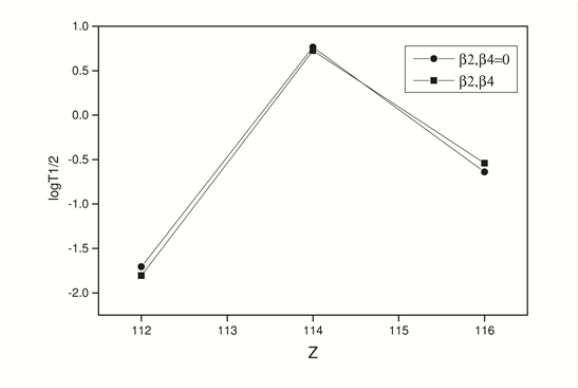

Figure 2. Deformation effect of Parents in α emission for even Z parents

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