Competition between α, β decay and Spontaneous Fission in $Z = 132$ Superheavy Nuclei

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Introduction

Spontaneous fission(SF) and alpha decay are the main decay modes for superheavy nuclei in their ground-states. The determination of half-lives in alpha decay and spontaneous fission serve as an important experimental signature for identifying the decay chains of superheavy nuclei(SHN) formed during fusion reactions.The SHN which have small alpha decay half-life compared to spontaneous fission half-life will survive fission and thus can be detected in the laboratory through alpha decay. Therefore, in order to produce superheavy nuclei artificially one needs a good theoretical understanding of dominant mode of decay in superheavy nuclei.Theoretically both these decay modes share the same underlying mechanism from physics point of view, i.e., the quantum tunnelling effect. As for as alpha decay is concerned, it is possible if the shell effect supplies the extra binding energy and increases the barrier height of the fission. However, the situation in spontaneous fission is very complex as it involves large uncertainities such as mass, charge number of two fragments, the number of emitted neutrons, released energy etc. Beta decay is another possible decay mode in SHN but as beta decay proceeds through weak interaction the process is slow and less favoured compared to spontaneous fission and alpha decay.
In this paper, we analyzed the competition between alpha decay, beta decay and spontaneous fission in $Z = 132$ superheavy nuclei and made an attempt to look for the dominant mode of decay in the even-even isotopic chain of superheavy nucleus under investigation.

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Formalism

We employed the relatistic mean-field theory with NL3* parametrization for calculation of binding energies which in turn is used to calculate the Q_α and Q_β values for the even-even isotopic chain $^{180-256}132$. In our calculations, we have used the Viola-Seaborg semi-empirical relation(VSS) [1], generalized liquid drop model(GLDM) proposed by Dasgupta-Schubert and Reyes [2] and Ni et al. [3] for studying the alpha decay half-lives. For calculating the spontaneous fission(SF) half-life we used the phenomenological formula proposed by Ren and Xu [4]. The estimation of beta decay half-life is accomplished by the empirical formula of Fiset and Nix [5].

Results and conclusion

A comparative study of alpha decay,beta decay and spontaneous fission is made for even-even isotopic chain of $Z = 132$ in the mass number range 312 to 388 using the semi-empirical relations mentioned in the last section. The figure 1 and table 1 depicts the comparison of the calculated alpha decay, beta decay and spontaneous fission half-lives against mass number of even-even isotopes of the superheavy nuclei under investigation. From the calculations, it is obvious that the alpha decay is the main decay mode upto even-even isotope $^{348}132$ and the half-lives predicted by the three phenomenological formulae are in good agreement with each other. From $^{350}132$ onwards the spontaneous fission is the main decay mode because of the heavy mass number of the isotopes. In the beta decay study of the nucleus, the Q_β values calculated using relativistic mean-field framework with NL3* parameter set are in close agreement with

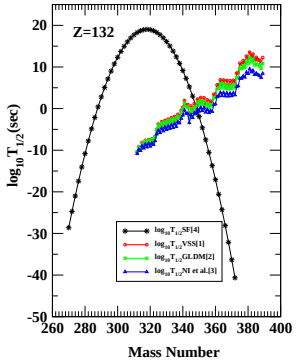

FIG. 1: log$T_{\frac{1}{2}}$(alpha decay [1–3] and spontaneous fission [4]) plotted against mass number for even-even isotopes of $Z = 132$ in the mass range 312 and 388.

TABLE I: Comparison of alpha decay and spontaneous fission half-lives for even-even isotopes with Z=132

A	Z	Q_α	Q_β	$log_{10}T_{1/2}$(sec)				
				VSS	GLDM	NI et.al.	SF	β-decay [5]
312	132	17.70	11.07	-9.49	-10.33	-10.82	18.27	-0.18
314	132	17.14	10.82	-9.68	-9.56	-10.12	18.69	-0.04
316	132	16.68	10.50	-8.98	-8.90	-9.53	18.94	0.14
318	132	16.48	9.89	-8.67	-8.63	-9.26	19.03	0.49
320	132	16.34	8.58	-8.45	-8.44	-9.07	18.95	1.30
322	132	16.04	8.17	-7.98	-8.01	-8.67	18.71	1.59
324	132	14.38	7.95	-5.00	-5.10	-6.13	18.30	1.75
326	132	14.19	7.36	-4.63	-4.77	-5.82	17.73	2.19
328	132	13.95	6.76	-4.15	-4.33	-5.41	17.00	2.67
330	132	13.75	6.07	-3.75	-3.95	-5.06	16.10	3.28
332	132	13.61	5.34	-3.45	-3.70	-4.81	15.03	3.99
334	132	13.49	4.65	-3.20	-3.48	-4.59	13.80	4.75
336	132	13.36	4.14	-2.92	-3.24	-4.36	12.41	5.38
338	132	12.89	3.91	-1.90	-2.26	-3.49	10.86	5.69
340	132	11.97	3.66	0.30	-0.107	-1.60	9.14	6.05
342	132	11.77	2.77	0.82	0.364	-1.16	7.25	7.49
344	132	12.85	2.75	-1.81	-2.280	-3.41	5.20	7.54
346	132	12.26	2.90	-0.39	-0.903	-2.20	2.99	7.27
348	132	11.85	2.55	0.63	0.086	-1.31	0.62	7.93
350	132	11.55	2.17	1.42	0.837	-0.64	-1.91	8.73
352	132	11.50	1.82	1.56	0.938	-0.52	-4.62	9.58
354	132	11.65	1.42	1.13	0.479	-0.89	-7.48	10.72
356	132	11.71	-1.05	1.00	0.314	-1.00	-10.56	9.67
358	132	11.57	0.89	1.34	0.624	-0.71	-13.70	12.66
360	132	10.82	0.57	3.45	2.686	1.08	-17.00	14.23
362	132	10.10	0.14	5.70	4.88	3.00	-20.59	17.53
364	132	10.06	-0.37	5.83	4.97	3.11	-24.27	-
366	132	10.10	-0.75	5.70	4.81	3.00	-28.12	-
368	132	10.11	-1.01	5.66	4.74	2.97	-32.13	-
370	132	10.09	-1.32	5.76	4.81	3.05	-36.31	16.06
372	132	10.02	-1.66	5.99	5.01	3.25	-40.65	13.90
374	132	9.28	-2.19	8.56	7.53	5.42	-45.15	11.62
376	132	8.75	-2.50	10.66	9.58	7.24	-49.82	10.61
378	132	8.67	-2.83	10.99	9.88	7.52	-54.65	9.70
380	132	8.43	-3.16	12.00	10.80	8.38	-59.64	8.90
382	132	8.32	-3.57	12.44	11.25	8.75	-64.79	8.05
384	132	8.50	-4.16	11.70	10.49	8.12	-70.11	7.00
386	132	8.48	-4.48	11.75	10.50	8.16	-75.60	6.50
388	132	8.68	-5.05	10.91	9.642	7.45	-81.24	5.70

finite range droplet model(FRDM) values. In figure 2, we have plotted the Q_β values and $T_{\frac{1}{2}}(\beta)$ for the isotopic chain under study using the semi-empirical relation proposed by Fiset and Nix [5]. We noticed that the half-life time in beta decay is very large ranging from -0.18(^{312}132) to 17.53(^{362}132) compared to alpha decay and spontaneous half-lives and hence is a very rare decay mode. Further, we noticed that the alpha half-live calculated from [3] and beta half-life estimated using [4] are close to each other in case of ^{378,380}132. As mentioned earlier the dominant decay mode is spontaneous fission from^{350}132 onwards, we witnessed a competition between alpha and beta decays in ^{382,384,386,388}132, wherein the dominant decay mode spontaneous fission is followed by beta decay.

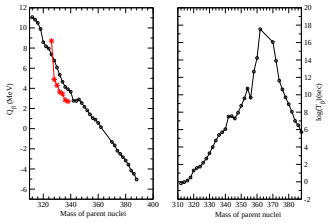

FIG. 2: Q_β and log(T_β)(sec) [5] plotted against the mass number for even-even isotopes of $Z = 132$ in the mass range 312 to 388.

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