Competition between α-decay and Spontaneous Fission (SF) in Z = 126 Superheavy Nuclei

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Introduction

Alpha decay and Spontaneous fission are the major modes of decay for nuclei in their ground states in the superheavy region. The process of α-decay is described by quantum tunneling of the alpha particle through coulomb barrier. However, the phenomenon of spontaneous fission occurs because of large uncertainties involved in masses, charges of the two fragments and energy released during the process. The theoretical predictions of half-lives in alpha decay and spontaneous fission provides an undeniable base to identify the decay chains of superheavy nuclei formed during fusion reactions. Superheavy nuclei with smaller alpha decay half-life than spontaneous fission half-life will survive fission and thus can be detected through alpha decay. So, we have tried to predict more prominent decay mode of Z = 126 within the mass range 280≤A≤380 by analyzing the competition between α-decay and spontaneous fission.

Formalism

We have employed axially deformed relativistic mean field (RMF) theory using NL3 [1] effective force to calculate binding energies which in turn are used to compute the α-decay energies, Q_α, used as inputs for estimating the α-decay half-lives for the isotopic chain 280≤A≤380 of Z = 126 superheavy nuclei. The α-decay half-lives are calculated using semi-empirical relation by Viola-Seaborg-Sobiczewski (VSS) [2], Royer [4], Brown [3] and Ni *et. al.* [5]. Another relation based on generalized liquid drop model (GLDM), proposed by Dasgupta-Schubert and Reyes [6], is also used to calculate α-decay half-lives. The estimation of spontaneous fission (SF) half-life is carried out using the phenomenological formula proposed by Ren *et. al.* [7].

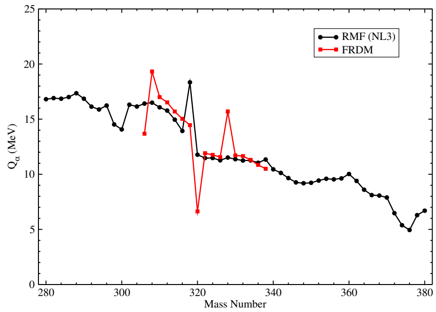

FIG. 1: α-decay energies of even-even Z=126 in the mass range 280 to 380.

Results and Conclusion

A comparative study of alpha decay and spontaneous fission is made for even-even Z = 126 nuclei in the mass range 280 to 338 using the aforementioned semiempirical relations. In figure 1, we have plotted alpha decay energies,Q_α, of the even-even isotopes of Z = 126 against their mass number. The values of Q_α, calculated using RMF theory and taken from finite range droplet model (FRDM) [8] data, match with each other for most of the isotopes. Figure 2 depicts the comparison of the calculated alpha decay and spontaneous fission half-lives of nuclei under investigation. It can be observed that the α-decay is the preferred decay mode in the mass range 294 to 314. The α-decay half-life calculated using the semimemperical relations are in good agreement with each other but doesn't show a very good agreement with the predictions of finite range droplet model (FRDM). The reason for disagreement is that $T^{\alpha}_{1/2} \propto 10^{\frac{1}{\sqrt{Q_\alpha}}}$

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TABLE I: Decay energies (in MeV) and half-lives (in seconds) of α-decay and spontaneous fission for even-even Z = 126 nuclei and prediction of mode of decays is given.

Nuclei	Q_α^{RMF}	Q_α^{FRDM}	$\log(T_{1/2}^{\alpha})$						$\log(T_{1/2}^{SF})$	Mode of
			VSS	Royer	Brown	Ni et. al.	GLDM	FRDM	Ren-Xu	decay
$^{290}126$	16.852		-10.46	-9.62	-9.46	-10.20	-10.93		-44.23	SF
$^{292}126$	16.136		-9.39	-8.59	-8.54	-9.17	-10.01		-16.28	SF
$^{294}126$	15.879		-8.99	-8.23	-8.20	-8.81	-9.67		7.10	α
$^{296}126$	16.235		-9.54	-8.82	-8.68	-9.40	-10.14		25.99	α
$^{298}126$	14.518		-6.68	-6.01	-6.22	-6.59	-7.69		40.49	α
$^{300}126$	14.068		-5.84	-5.21	-5.51	-5.79	-6.98		50.69	α
$^{302}126$	16.311		-9.66	-9.04	-8.78	-9.63	-10.24		56.67	α
$^{304}126$	16.145		-9.40	-8.82	-8.56	-9.41	-10.02		58.51	α
$^{306}126$	16.411	13.68	-9.81	-9.26	-8.91	-9.85	-10.37	-5.08	56.30	α
$^{308}126$	16.496	19.32	-9.94	-9.43	-9.01	-10.02	-10.48	-13.69	50.12	α
$^{310}126$	16.07	17.00	-9.29	-8.81	-8.46	-9.41	-9.92	-10.68	40.03	α
$^{312}126$	15.776	16.52	-8.82	-8.39	-8.06	-8.98	-9.53	-9.98	26.12	α
$^{314}126$	14.952	15.69	-7.45	-7.06	-6.88	-7.65	-8.35	-8.68	8.46	α
$^{316}126$	13.931	15.03	-5.58	-5.23	-5.28	-5.82	-6.75	-7.59	-12.88	SF
$^{318}126$	18.339	14.46	-12.49	-12.13	-11.20	-12.74	-12.66	-6.57	-37.82	SF
$^{320}126$	11.774	6.63	-0.86	-0.61	-1.24	-1.20	-2.72	>18.60	-66.31	SF
$^{322}126$	11.47	11.91	-0.09	0.12	-0.58	-0.46	-2.06	-1.20	-98.28	SF
$^{324}126$	11.476	11.76	-0.10	0.07	-0.59	-0.52	-2.07	-0.83	-133.66	SF
$^{326}126$	11.263	11.56	0.46	0.59	-0.11	0.01	-1.59	-0.30	-172.38	SF
$^{328}126$	11.517	15.69	-0.21	-0.10	-0.68	-0.69	-2.16	-8.69	-214.40	SF
$^{330}126$	11.369	11.71	0.18	0.25	-0.35	-0.34	-1.83	-0.69	-259.64	SF
$^{332}126$	11.248	11.65	0.50	0.53	-0.08	-0.06	-1.56	-0.55	-308.05	SF
$^{334}126$	11.259	11.31	0.47	0.47	-0.10	-0.12	-1.59	0.32	-359.58	SF
$^{336}126$	11.046	10.85	1.04	1.01	0.39	0.41	-1.09	1.57	-414.16	SF
$^{338}126$	11.339	10.50	0.26	0.20	-0.28	-0.40	-1.77	2.60	-471.74	SF
$^{340}126$	10.449		2.75	2.64	1.85	2.04	0.36		-532.28	SF
$^{342}126$	10.125		3.73	3.58	2.69	2.99	1.20		-595.71	SF
$^{344}126$	9.653		5.26	5.07	4.00	4.47	2.51		-661.99	SF
$^{346}126$	9.266		6.59	6.36	5.14	5.77	3.65		-731.07	SF
$^{348}126$	9.187		6.88	6.61	5.39	6.02	3.89		-802.90	SF
$^{350}126$	9.227		6.73	6.44	5.26	5.84	3.77		-877.43	SF
$^{352}126$	9.428		6.02	5.70	4.66	5.10	3.16		-954.62	SF
$^{354}126$	9.594		5.46	5.11	4.17	4.51	2.68		-1034.42	SF
$^{356}126$	9.538		5.65	5.26	4.33	4.66	2.84		-1116.78	SF
$^{358}126$	9.625		5.35	4.94	4.08	4.34	2.59		-1201.67	SF
$^{360}126$	10.024		4.05	3.62	2.97	3.01	1.48		-1289.05	SF

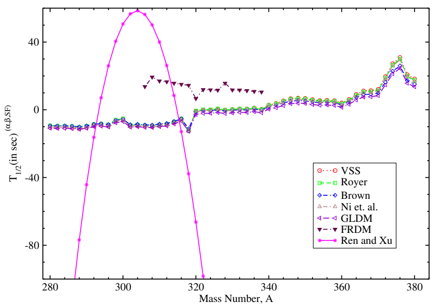

FIG. 2: $\log(T_{1/2})$ for α-decay and SF plotted for even-even Z = 126 nuclei with 280≤A≤380.

indicating that a small change in Q_α creates a big difference in $T_{1/2}^{\alpha}$ as reflected in the table. The isotopes with A < 294 and A > 314 are found to be spontaneously fissile in their ground sate due to their heavy mass. The calculated alpha decay half-lives for 290≤A≤360, using VSS, GLDM, Brown, Royer and Ni *et al.* and spontaneous decay half-lives are tabulated in table 1. As few nuclei are predicted to have α-decay half-lives of few μs, thus present calculation suggests that there is a possibility to synthesize the Z = 126 superheavy nuclei by observing the α-decay.

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