Theoretical Investigation of α-decay Chain of Superheavy Isomer ^{259}Rf

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Theoretical studies on synthesis of new superheavy nuclei (SHN) are expected to bring in the new opportunities and more exciting times in the arena of experimental activities. In this particular region of periodic chart, α-decay is the dominant decay mode in which transitions take place mainly from ground-to-ground states, and also in a few isomeric states. However, the information about the excited-state structure of SHN is still scarce and the works on structure calculations are merely a few. Some investigations have highlighted that the isomeric states may be a key factor in the enhanced stability of the SHN, with isomeric life-times exceeding those of the ground states [1, 2]. A huge amount of data is now available [3], motivating us to perform the study of life-times of α-decay for the isomers which are located in the superheavy region.

In the present work, we have estimated the α-decay half-lives for the decay chain of superheavy isomer ^{259}Rf^p. The half-lives are calculated by employing a few latest empirical formulas [4–6] which are first probed on known isomers that decay via α-emission. The QF formula [6] is found more accurate in estimating the half-lives for the known isomers and therefore has been applied to estimate the half-lives of α-transitions ($T^{\alpha}_{1/2}$) for the decay chain of superheavy isomer ^{259}Rf^p.

The QF Formula is represented as,

$$log_{10}T^{\alpha}_{1/2} = a\sqrt{\mu}\left(\frac{Z_d^{0.6}}{\sqrt{Q}}\right)^2 + b\sqrt{\mu}\left(\frac{Z_d^{0.6}}{\sqrt{Q}}\right) + c + dl(l+1) \quad (1)$$

where, μ is the reduced mass which is given by $A_dA_\alpha/(A_d+A_\alpha)$ with A_d and A_α are the mass numbers of daughter nucleus and α-particle, respectively. Likewise, Z_d and Z_α represent atomic number of daughter nucleus and α-particle, respectively.

Q (in MeV) is the energy released in α-decay from the jp state of parent nucleus (with excitation energy E$_{jp}$) to the id state of daughter nucleus (with excitation energy E$_{id}$) and it is calculated as [7]:

$$Q_{j\to i} = Q_{g.s.\to g.s.} + E_{jp} - E_{id} \quad (2)$$

where $Q_{g.s.\to g.s.}$ is the energy released in ground-to-ground α-decay.

In Table I, we have listed α-decay half-lives for the nuclei corresponding to the decay chain of ^{259}Rf^p calculated by employing QF formula [6], Royer formula [4], and MUDL formula [5]. These half-lives are compared with experimental half-lives, which are tabulated in column sixth of this table and taken from NUBASE2020 [8]. It is clear from the table that QF formula agrees well with the experimental half-lives. To calculate the half-lives, we have used the Q values which are mentioned in second column and taken from AME2020 [9] in Eqn. (2). Spins and parities are also taken from NUBASE2020 [8], mentioned in column third and fourth for the parent and daughter nuclei, respectively. The minimum angular momentum taken away by the α-particle, is calculated by using the standard selection rules [10].

We have also plotted a block diagram in the Fig. 1 for this decay chain in which the estimated half-lives from QF formula are mentioned in red colour. The half-life ($T^{\alpha}_{1/2}$) of undetected superheavy isomer ^{259}Rf^p is found

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TABLE I: Comparison between the calculated and experimental α-decay half-lives for isomeric α-decay chain of superheavy isomer ^{259}Rf^{p}. Superscript m and p define the first and third excited state, respectively.

Parent Nuclei	Q_α (MeV)	j_p	j_d	l	$\log_{10} T_{1/2}$(sec.)			
					Exp.	QF	Royer	MUDL
^{259}Rf^{p}	8.98	$7/2^+$	$11/2^-$	3	-	0.47	1.29	1.53
^{255}No^{m}	8.64	$11/2^-$	$9/2^-$	2	0.00	0.64	1.34	1.60
^{251}Fm	7.43	$9/2^-$	$7/2^+$	1	4.28	3.85	4.68	5.05
^{247}Cf	6.50	$7/2^+$	$5/2^+$	2	4.05	-	-	-

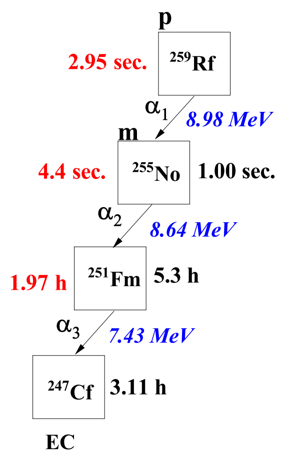

FIG. 1: α-decay half-lives for the decay chain of ^{259}Rf^{p} calculated by the QF formula (red numbers) are shown. Experimental half-lives (black numbers) and Q-values (blue numbers) are taken from NUBASE2020 [8] and AME2020 [9]

to be 2.95 sec. (short lived) which is in the experimental reach and might be crucial for near future experiments. This decay chain contains 3 consecutive α-decays and the last candidate decays via electron capture process. It would be interesting to test QF formula for the other isomeric (α-decay) chains in superheavy region. A detailed work on the α-decaying superheavy isomers is in progress and will be reported as a full paper.

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References

[1] F. Xu, *et al.*, Phys. Rev. Lett. **92**, 252501 (2004).
[2] R.-D. Herzberg, *et al.*, Nature **442**, 896 (2006).
[3] A. K. Jain, *et al.*, Nuclear Data Sheets **128**, 1-130 (2015): Update arXiv:2208.01028 [nucl-th].
[4] J.-G. Deng, H.-F. Zhang, and G. Royer, Phys. Rev. C **101**, 034307 (2020).
[5] A. Soylu and C. Qi, Nuclear Physics A **1013**, 122221 (2021).
[6] G. Saxena, A. Jain, and P. K. Sharma, Phy. Scr. **96**, 125304 (2021).
[7] V. Y. Denisov and A. Khudenko, Physical Review C **80**, 034603 (2009).
[8] F. G. Kondev, *et al.*, Chinese Physics C **45**, 030001 (2020).
[9] Meng Wang, *et al.*, Chinese Physics C **45**, 030003 (2020).
[10] V. Y. Denisov and A. Khudenko, Atomic Data and Nuclear Data Tables **95**, 815 (2009).