Theoretical Investigation of α-decay in Superheavy Isomers

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ABSTRACT

Theoretical studies on synthesis of new superheavy nuclei are expected to bring in 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 along with in or from isomeric state. In the present work, we have estimated half-lives of α-transitions belonging to the isomeric states in the superheavy nuclei with proton number Z>100. The half-lives are calculated by employing few latest empirical formulas. The QF-formula is found more accurate in estimating the half-lives for the known isomers. We have also calculated the half-lives in a few cases, predicted to be isomers in NUBASE2020 with no known half-lives. Such results may be validated in future experiments at modern-day sophisticated experimental facilities.

Keywords: Superheavy Nuclei, α-decay, Isomeric State.

Background

- α-decay is the dominant and important decay mode because the synthesis of new superheavy nuclei (SHN) is mainly governed by α-decay.

Motivation

- Some investigation already indicated that the isomeric state may be a key factor in the enhanced stability of the SHN, with isomeric lifetimes exceeding those of the ground states and recent compilation of isomers by Jain *et al.* [1] has invoked us to perform the study of lifetimes of α-decay for the isomer which are located in the superheavy region.

Method

- In the present work, we apply QF-formula [2] to calculate α-decay logarithmic half-lives of SHN in isomeric states.
- Qα values for the isomeric state are calculated by formula as mentioned in Ref. [3] using Q values from NUBASE2020. The angular momentum l taken away by the alpha particle is calculated by standard selection rules [4] using spin and parity of parent and daughter nuclei as given in NUBASE2020 [5].

Results

- As a first and essential step, we test the QF-formula for 66 α-decay transitions in isomeric states [5] and compare the results with that of the results of very recent Royer's formula [6] and modified UDL (MUDL) formula [7].
- Using the more precise formula among three, we have calculated the logarithmic half-lives of α-decay in isomeric states of 12 SHN mentioned in NUBASE2020 [5] and the possibility of α-decay transition belong to isomers in superheavy region.

SUMMARY:

QF-formula works well than the Royer's formula and MUDL formula to reproduce the α-decay half-lives in superheavy isomers. We have calculated the α-decay half-lives for the predicted isomers in NUBASE2020 with no known half-lives until date.

QF-Formula

$$\log_{10} T_{\frac{1}{2}} = a\sqrt{\mu}\left(\frac{Z_d^{0.6}}{\sqrt{Q_\alpha}}\right)^2 + b\sqrt{\mu}\left(\frac{Z_d^{0.6}}{\sqrt{Q_\alpha}}\right) + \mathrm{c} + \mathrm{dl(l+1)}$$

Royer-Formula

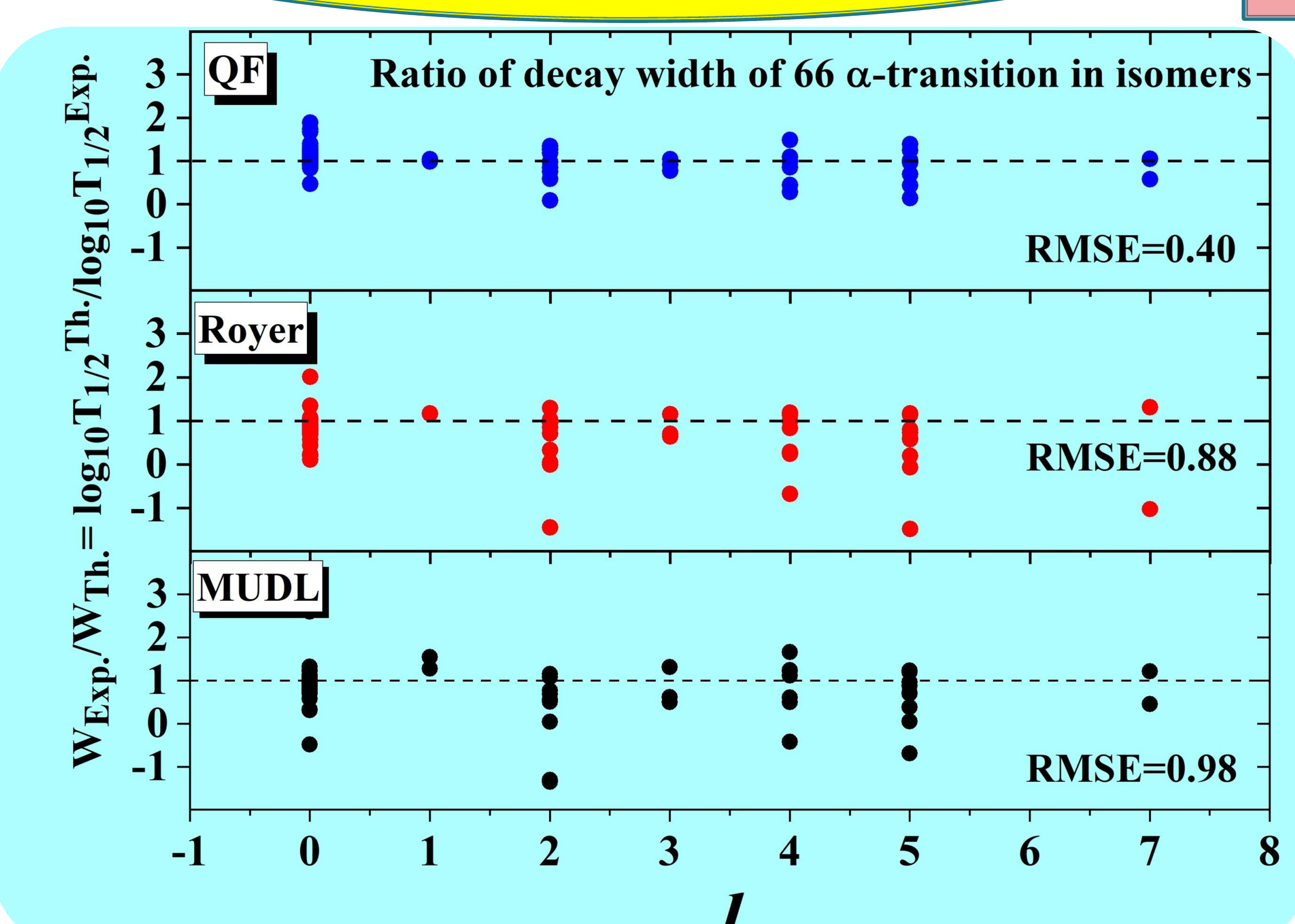
$$\log_{10} T_{\frac{1}{2}} = a + bA^{\frac{1}{6}}\sqrt{Z} + \frac{cZ}{\sqrt{Q_\alpha}} + \mathrm{dl(l+1)} + \mathrm{h}$$

MUDL-Formula

$$\log_{10} T_{\frac{1}{2}} = aZ_\alpha Z_d\sqrt{\frac{\mu}{Q_\alpha}} + b\sqrt{\mu Z_\alpha Z_d(A_\alpha^{\frac{1}{3}} + A_d^{\frac{1}{3}})} + c + d\sqrt{\mu Z_\alpha Z_d(A_\alpha^{\frac{1}{3}} + A_d^{\frac{1}{3}})}\sqrt{l(l+1)} + e\sqrt{I(I+1)} + f\mu[1-(-1)^l]$$

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

$$x = a\sqrt{\mu}\left(\frac{Z_d^{0.6}}{\sqrt{Q_\alpha}}\right)^2 + b\sqrt{\mu}\left(\frac{Z_d^{0.6}}{\sqrt{Q_\alpha}}\right), y = \log_{10} T_{\frac{1}{2}}^{Exp.} - c - dl(l+1)$$



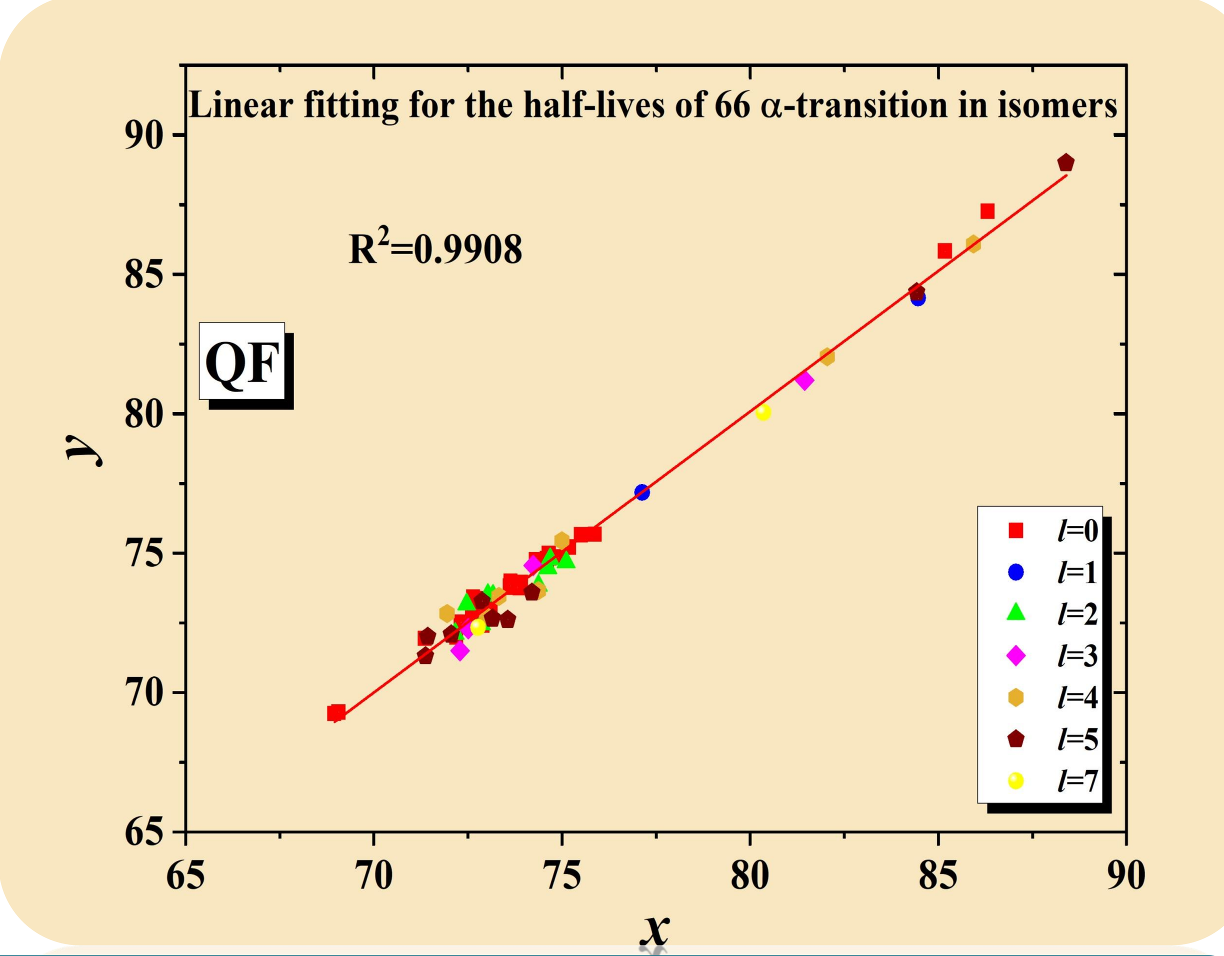


Table 1: Comparison between calculated and experimental α-decay half-lives in superheavy isomers.

α-transition	Q_α (MeV)	j_p	j_d	l	$\log_{10} T_{1/2}$(sec.) Exp.	QF	Royer	MUDL
$^{258}Md \to {}^{254}Es^m$	7.19	8^-	2^+	7	6.65	6.98	8.75	8.04
$^{257}Lr \to {}^{253}Md^p$	9.02	$7/2^-$	$1/2^-$	4	0.78	0.34	0.77	1.29
$^{261}Rf^m \to {}^{257}No^p$	8.42	$11/2^-$	$9/2^+$	1	1.87	1.84	2.19	2.89
$^{259}Sg \to {}^{255}Rf^m$	9.62	$11/2^-$	$5/2^+$	3	-0.40	-0.71	-0.20	0.38
$^{263}Sg^m \to {}^{259}Rf$	9.46	$7/2^+$	$3/2^+$	2	-0.38	-0.47	-0.12	0.51
$^{263}Hs \to {}^{259}Sg^m$	10.65	$3/2^+$	$1/2^+$	2	-3.05	-2.99	-2.61	-2.09
$^{263}Hs^m \to {}^{259}Sg^m$	10.98	$11/2^-$	$1/2^+$	5	-3.00	-2.93	-2.18	-2.10
$^{265}Hs \to {}^{261}Sg^m$	10.37	$3/2^+$	$7/2^+$	2	-2.71	-2.29	-1.94	-1.38
$^{265}Hs^m \to {}^{261}Sg^m$	10.60	$11/2^-$	$7/2^+$	3	-3.44	-2.65	-2.21	-1.70

Table 2: The calculated half-lives for the predicted superheavy isomer in NUBASE2020.

α Transition	Q_α (MeV)	j_p	j_d	l	$\log_{10} T_{1/2}$ (Sec.)	α Transition	Q_α (MeV)	j_p	j_d	l	$\log_{10} T_{1/2}$ (Sec.)
$^{255}Fm^p \to {}^{251}Cf^m$	7.10	$9/2^+$	$11/2^-$	1	5.07	$^{259}Rf^q \to {}^{255}No^m$	9.13	$9/2^+$	$11/2^-$	1	-0.32
$^{255}Fm^p \to {}^{251}Cf$	7.47	$9/2^+$	$1/2^+$	4	4.35	$^{259}Rf^q \to {}^{255}No^p$	9.24	$9/2^+$	$7/2^+$	2	-0.50
$^{257}No^p \to {}^{253}Fm^n$	8.43	$9/2^+$	$11/2^-$	1	1.18	$^{259}Rf^p \to {}^{255}No^m$	8.98	$7/2^+$	$11/2^-$	3	0.47
$^{257}No^p \to {}^{253}Fm^m$	8.64	$9/2^+$	$7/2^+$	2	0.66	$^{259}Rf^p \to {}^{255}No$	9.19	$7/2^+$	$1/2^+$	4	0.14
$^{257}No^p \to {}^{253}Fm$	8.78	$9/2^+$	$1/2^+$	4	0.73	$^{259}Rf^q \to {}^{255}No^m$	9.34	$9/2^+$	$1/2^+$	4	-0.28
$^{259}Rf^p \to {}^{255}No^p$	9.09	$7/2^+$	$7/2^+$	0	-0.28	$^{262}Sg^p \to {}^{258}Rf$	10.46	9^-	0^+	10	0.57

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