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Ground state α-transition of heavy nuclei using semi-empirical formulae

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Introduction

Hitherto, the experiments involving the synthesis of most trans-actinides have been successfully carried out [1]. Presently, the search of superheavy nuclei is at the fore-front of the quest in nuclear physics. Most often, the decay energies and the half-lives are used as theoretical probes [2]. Theoretically, several semi-empirical formulae has been employed for the investigation of the α-decay half-lives.

The present study is geared at examining different semi-empirical formula that can effectively estimate the decay half-lives at the known region of the nuclear landscape. This will further give the hope of applying the most potent formula for the predictions in the unknown regimes. Thus we have employed four semi-empirical formulae, to compute the decay half-lives of the considered α-emitting systems. Mainly, the Q-α-values are calculated from RMF binding energy mass table using the PC-PK1 parameter set [3] (with or without nuclear rotation) and compared with those from the experimental data.

Theoretical formalism

To estimate the decay half-lives, the semi-empirical used here include:
(1). Modified Viola-Seaborg semi-empirical formula (MVS) [4]: contains two asymmetry terms and hold a linear relationship with the α-decay half-lives in the form

$$\log_{10} T_{1/2}^{MVS} = (aZ+b)Q_\alpha^{-1/2}+cZ+d+eI+fI^2. \tag{1}$$

where all constants are given in Ref. [4]
(2). Modified scaling law of Brown (MSLB) [4]: is a similar α-decay formula that incorporates two asymmetry terms in the expression

$$\log_{10} T_{1/2}^{MSLB} = aZ_d^{0.6}Q_\alpha^{-1/2}+b+cI+dI^2 \tag{2}$$

whose constants are given the Ref. [4].
(3). YQZR formula (YQZR) [5]: is predicated on the NRDX formula with an addition of the angular momentum (l) term. following all constants in the Ref. [5], Its expression is given as

$$\log_{10} T_{1/2}^{YQZR} = a\sqrt{\mu}Z_dZ_\alpha Q_\alpha^{-1/2} + b\sqrt{\mu}(Z_dZ_\alpha)^{1/2} + c\frac{l(l+1)}{\mu\sqrt{Z_dZ_\alpha A_d^{1/6}}} + d. \tag{3}$$

(4). Modified YQZR formula (MYQZR) [4]: is the modified form of the aforementioned YQZR formula.

$$\log_{10} T_{1/2}^{MYQZR} = a\sqrt{\mu}Z_dZ_\alpha Q_\alpha^{-1/2} + b\sqrt{\mu}(Z_dZ_\alpha)^{1/2} + c\frac{l(l+1)}{\mu\sqrt{Z_dZ_\alpha A_d^{1/6}}} + d + eI + fI^2 \tag{4}$$

Also see Ref. [4] for the fitting constants.

Result and Discussions

The ground state to ground state α-transition of ${}^{142}_{58}$Ce, ${}^{144}_{60}$Nd, ${}^{146}_{62}$Sm, ${}^{148}_{64}$Gd,

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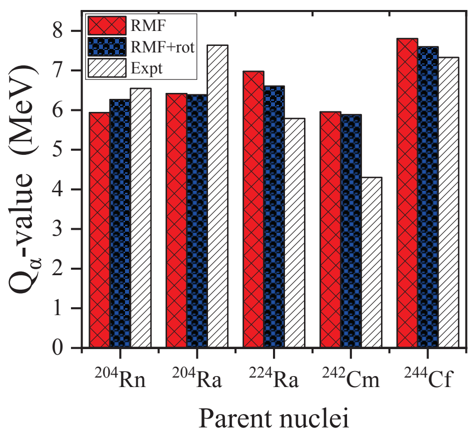

FIG. 1: The calculated decay energy (Q_α-values) for considered system for RMF and RMF+rot using the PC-PK1 parameter set in comparison with the experimental data [6].

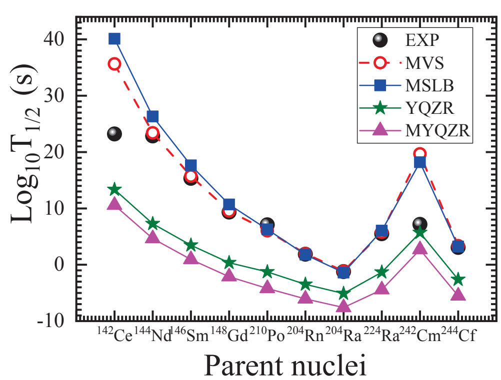

FIG. 2: The predicted logarithm of half-lives against mass number using four semi-empirical formulae compared with experimental half-lives[6] for the considered system .

$^{210}_{84}$Po, $^{204}_{86}$Rn, $^{204}_{88}$Ra $^{224}_{88}$Ra, $^{242}_{96}$Cm and$^{244}_{98}$Cf is examined using different semi-empirical formulae. This gives a ground to inspect the relative dependence of each decay formula on their respective constituent. The energy available for the α-decay process is otherwise called the Q_α-value. Thus, the accurate estimation of the Q_α-value is central to the calculation/prediction of the experimentally measured decay half-lives. In Fig. 1, the Q_α-values are calculated from Ref. [3] for RMF only (red shaded cross marks) and without nuclear rotation effect) and those from the experimental binding energies [6]. Relatively, the RMF estimate (with and without rotation) may not the best compromise in this region of study. However, the inclusion of nuclear rotation shows a better consistence with the Q_α-values obtained from the experimental binding energies.

Fig. 2 presents the calculated logarithmic half-lives of the considered systems using the experimental Q_α-value (Q_α^{Expt}) for the sake of accuracy. It is quite apparent that the MVS (red open circle and dash lines) gives a better match with the experimental half-lives (black spheres). The MSLB formula (blue squares) also produces a reasonable fitting. However, The calculated half-lives from both YQZR and the MYQZR shows are relatively far from the experimental data. The accuracy can be attributed to the inclusion of the asymmetry terms in both MVS and MSLB formulae. This disparity probably ensues as a result of cancellation of the unique properties (angular momentum l) of the YQZR and MYQZR at the ground state where $l = 0$. Thus, we conclude that parametrization and formulation plays essential roles in the the prediction of the α-decay half-lives.

Acknowledgments

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