Global potential for α+nucleus systems and prediction of α-decay half-lives and Q_α values of superheavy nuclei

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An approach we have proposed recently [1] for calculation of Q_α energy and decay half-life $T^\alpha_{1/2}$ on the α decay of radioactive heavy ions is applied to the evaluation of these two important parameters for the nuclei in the superheavy region Z=112-118 for which experimental data are not available [2].

The potential which simulates the total effective potential of a typical α+nucleus system is expressed analytically as a function of radial distance r as follows [1].

$$V(r) = \begin{cases} V_{01}\left\{\lambda_1^2[B_0 + (B_1 - B_0)(1 - y_1^2)] + \xi_1\right\} \\ \text{if } 0 < \text{r} < \text{R}_1 \\ V_{02}\left\{\lambda_2^2 B_2(1 - y_2^2) + \xi_2\right\} \\ \text{if } \text{r} \geq \text{R}_1, \end{cases} \tag{1}$$

where
$\xi_1 = (\frac{1-\lambda_1^2}{4})[5(1-\lambda_1^2)y_1^4-(7-\lambda_1^2)y_1^2+2](1-y_1^2)$
$\xi_2 = (\frac{1-\lambda_2^2}{4})[5(1-\lambda_2^2)y_2^4-(7-\lambda_2^2)y_2^2+2](1-y_2^2)$.

Here, V_{01} and V_{02} are the strength of the potential in MeV. Denoting the mass of the particle moving under the potential by m, we use dimensionless variable $\rho_n = (r - R_1)b_n$ with $b_n = (\frac{2m}{\hbar^2}V_{0n})^{1/2}$, n= 1, 2, such that ρ_n is related to the new variable y_n as $\rho_n = \frac{1}{\lambda_n^2}[tanh^{-1}y_n - (1-\lambda_n^2)^{1/2}tanh^{-1}(1-\lambda_n^2)^{1/2}y_n]$.

The α+nucleus potential which can be obtained by calculations based on mean-field theoretic approaches [3], is closely reproduced by our analytically solvable potential [Eq. (1)] by fixing the values of the parameters namely r_0, a, B_0, $b_1 = \sqrt{B_1}A_t^{-1/3}$, and λ_1. It is obvious that different parent nuclei decaying through α decay mode would experience different interaction potentials for their corresponding α+daughter systems depending on the values of mass number A and atomic number Z of the parent nucleus. The variation in the potential is achieved by changing the value of one of the above parameters namely λ_1 as a function of Z and neutron number N (= A−Z) [2] while the values of remaining four parameters are fixed at r_0=0.97 fm, a=1.6 fm, B_0=−78.75, and b_1=0.82.

$$\lambda_1 = \left\{2 - \frac{1}{1+exp[c_z(Z-Z_0)]}\right\} + D\left\{1 - exp[c_n(N-N_0)]\right\}. \tag{2}$$

where Z_0=115 is the Z value of a nucleus in the middle of the series of nuclei Z=112−118 under consideration, c_z=0.2 D=0.3, c_n=0.15, and N_0 indicates the largest N of the nucleus in the series of isotopes.

By using the input potential specified by the value of the parameter λ_1 given by (2) along with the values of fixed parameters stated above, the results of Q_α and $T^\alpha_{1/2}$ of any nucleus are calculated by our wave function method described in [1]. In Table I, we record these predicted results of Q_α and $T^\alpha_{1/2}$ of our present calculation denoted as $Q_\alpha^{(present)}$ and $T_{1/2}^{\alpha(present)}$, respectively, in the cases of nuclei with Z=112−118 for which experimental data are not available.

The calculated results of Q_α and $T^\alpha_{1/2}$ obtained by using the value of λ_1 decided by the global expression (2) along with the other fixed potential parameters are compared [2] with the corresponding experimental data available in some nuclei in the region with Z=112-118. It is found that our calculated results of $Q_\alpha^{(present)}$ explain the corresponding experimental $Q_\alpha^{(expt)}$ data very well. Hence, the global interaction potential for

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TABLE I Predicted results of Q_α energy and half-life $T^{\alpha}_{1/2}$ for α-decay of superheavy nuclei obtained using present formulation where values of potential parameters r_0=0.97 fm, a=1.6 fm, b_1=0.82, and B_0=−78.75 are kept same for all nuclei, and the values of the parameter λ_1 for different nuclei are obtained by using a global formula (2). Values of Q_α are expressed in MeV.

Nucleus	λ_1	$Q_\alpha^{(present)}$	$T_{1/2}^{\alpha(present)}$
^{295}118	1.6457	11.24	6.30 ms
^{293}118	1.7234	11.64	0.09 ms
^{295}117	1.5987	10.76	45 ms
^{292}117	1.7074	11.35	2.0 ms
^{295}116	1.5498	10.2734	0.41 s
^{294}116	1.5916	10.49	0.09 s
^{289}116	1.7279	11.31	1.23 ms
^{288}116	1.7449	11.43	0.68 ms
^{292}115	1.5000	9.96	1.4 s
^{291}115	1.5418	10.19	0.34 s
^{286}115	1.6780	11.03	3.0 ms
^{285}115	1.6950	11.15	1.5 ms
^{291}114	1.4502	9.51	13.7 s
^{290}114	1.4920	9.75	2.8 s
^{285}114	1.6282	10.61	15.4 ms
^{284}114	1.6452	10.73	7.6 ms
^{288}113	1.4013	9.18	65.4 s
^{287}113	1.4431	9.42	11.3 s
^{281}113	1.5963	10.44	19.8 ms
^{280}113	1.6110	10.56	10.1 ms
^{287}112	1.3543	8.72	873.5 s
^{286}112	1.3961	8.97	130 s
^{284}112	1.4631	9.40	6.6 s
^{282}112	1.5126	9.74	0.69 s
^{281}112	1.5324	9.88	0.28 s
^{280}112	1.5494	10.02	0.12 s

a α+nucleus system in our calculation is a genuine entity and the results of decay half-life $T^{\alpha}_{1/2}$ and Q_α energy predicted by using this potential are believed to provide reliable information for experiments on α decay of new nuclei in the superheavy region.

References

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