Global potential for $\alpha+$nucleus systems and prediction of $\alpha$-decay half-lives and $Q_\alpha$ values of superheavy nuclei

Basudeb Sahu*

Department of Physics, North Orissa University, Baripada-757003, INDIA

An approach we have proposed recently [1] for calculation of $Q_\alpha$ energy and decay half-life $T^{\alpha}_1/2$ on the $\alpha$ 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 $\alpha+$nucleus system is expressed analytically as a function of radial distance $r$ as follows [1].

$$V(r) = \begin{cases} V_{01} \{ \lambda_2^2 [B_0 + (B_1 - B_0)(1 - y^2_1)] + \xi_1 \} & \text{if } 0 < r < R_1 \\ V_{02} \{ \lambda_2^2 B_2 (1 - y^2_2) + \xi_2 \} & \text{if } r \geq R_1, \end{cases}$$

(1)

where

$$\xi_1 = \left(\frac{1-\lambda^2_2}{4}\right)5(1-\lambda_1^2)y_1^4 - (7-\lambda_1^2)y_1^2 + 2(1-y_1^2),$$

$$\xi_2 = \left(\frac{1-\lambda^2_2}{4}\right)5(1-\lambda_2^2)y_2^4 - (7-\lambda_2^2)y_2^2 + 2(1-y_2^2).$$

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 $b_n = (\frac{4\pi}{3}V_0n)^{1/2}$, $n = 1, 2$, such that $\rho_n$ is related to the new variable $y_n$ as

$$\rho_n = \frac{1}{\lambda_2^2} [\tanh^{-1} y_n - (1 - \lambda_2^2)^{1/2}\tanh^{-1}(1- \lambda_2^2)^{1/2} y_n].$$

The $\alpha+$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 $r_0$, $a$, $B_0$, $b_1 = \sqrt{\frac{1}{4\pi}}a_1^{1/3}$, and $\lambda_1$. It is obvious that different parent nuclei decaying through $\alpha$ decay mode would experience different interaction potentials for their corresponding $\alpha+$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 $\lambda_1$ or $\lambda_2$ 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 $b_1=0.82$.

$$\lambda_1 = \left\{ \frac{2 - c_2 e^{z_2(N - N_0)}}{1 + c_2 e^{z_2(N - N_0)}} \right\} + D \{ 1 - exp[c_3(N - N_0)] \},$$

(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, $c_2=0.2, D=0.3, c_3=0.15$, 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 $\lambda_1$ given by (2) along with the values of fixed parameters stated above, the results of $Q_\alpha$ 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 $Q_\alpha$ and $T^{\alpha}_1/2$ of our present calculation denoted as $Q^{(\text{present})}_\alpha$ and $T^{\alpha}_1/2^{(\text{present})}$, respectively, in the cases of nuclei with $Z=112-118$ for which experimental data are not available.

The calculated results of $Q_\alpha$ and $T^{\alpha}_1/2$ obtained by using the value of $\lambda_1$ 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 $Q^{(\text{present})}_\alpha$ explain the corresponding experimental $Q^{(\text{exp})}_\alpha$ data very well. Hence, the global interaction potential for

*Electronic address: bd_sahu@yahoo.com
TABLE I Predicted results of $Q_\alpha$ energy and half-life $T_{1/2}^{\alpha}$ for $\alpha$-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 $\lambda_1$ for different nuclei are obtained by using a global formula (2). Values of $Q_\alpha$ are expressed in MeV.

<table>
<thead>
<tr>
<th>Nucleus</th>
<th>$\lambda_1$</th>
<th>$Q_\alpha^{(\text{present})}$</th>
<th>$T_{1/2}^{\alpha}^{(\text{present})}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{295}$118</td>
<td>1.6457</td>
<td>11.24</td>
<td>6.30 ms</td>
</tr>
<tr>
<td>$^{293}$118</td>
<td>1.7234</td>
<td>11.64</td>
<td>0.09 ms</td>
</tr>
<tr>
<td>$^{295}$117</td>
<td>1.5987</td>
<td>10.76</td>
<td>45 ms</td>
</tr>
<tr>
<td>$^{292}$117</td>
<td>1.7074</td>
<td>11.35</td>
<td>2.0 ms</td>
</tr>
<tr>
<td>$^{295}$116</td>
<td>1.5498</td>
<td>10.2734</td>
<td>0.41 s</td>
</tr>
<tr>
<td>$^{294}$116</td>
<td>1.5916</td>
<td>10.49</td>
<td>0.09 s</td>
</tr>
<tr>
<td>$^{295}$116</td>
<td>1.7279</td>
<td>11.31</td>
<td>1.23 ms</td>
</tr>
<tr>
<td>$^{288}$116</td>
<td>1.7449</td>
<td>11.43</td>
<td>0.68 ms</td>
</tr>
<tr>
<td>$^{292}$115</td>
<td>1.5000</td>
<td>9.96</td>
<td>1.4 s</td>
</tr>
<tr>
<td>$^{291}$115</td>
<td>1.5418</td>
<td>10.19</td>
<td>0.34 s</td>
</tr>
<tr>
<td>$^{286}$115</td>
<td>1.6780</td>
<td>11.03</td>
<td>3.0 ms</td>
</tr>
<tr>
<td>$^{285}$115</td>
<td>1.6950</td>
<td>11.15</td>
<td>1.5 ms</td>
</tr>
<tr>
<td>$^{291}$114</td>
<td>1.4502</td>
<td>9.51</td>
<td>13.7 s</td>
</tr>
<tr>
<td>$^{290}$114</td>
<td>1.4920</td>
<td>9.75</td>
<td>2.8 s</td>
</tr>
<tr>
<td>$^{285}$114</td>
<td>1.6282</td>
<td>10.61</td>
<td>15.4 ms</td>
</tr>
<tr>
<td>$^{284}$114</td>
<td>1.6452</td>
<td>10.73</td>
<td>7.6 ms</td>
</tr>
<tr>
<td>$^{288}$113</td>
<td>1.4013</td>
<td>9.18</td>
<td>65.4 s</td>
</tr>
<tr>
<td>$^{287}$113</td>
<td>1.4431</td>
<td>9.42</td>
<td>11.3 s</td>
</tr>
<tr>
<td>$^{281}$113</td>
<td>1.5963</td>
<td>10.44</td>
<td>19.8 ms</td>
</tr>
<tr>
<td>$^{280}$113</td>
<td>1.6110</td>
<td>10.56</td>
<td>10.1 ms</td>
</tr>
<tr>
<td>$^{287}$12</td>
<td>1.3543</td>
<td>8.72</td>
<td>87.35 s</td>
</tr>
<tr>
<td>$^{286}$12</td>
<td>1.3961</td>
<td>8.97</td>
<td>130 s</td>
</tr>
<tr>
<td>$^{284}$12</td>
<td>1.4631</td>
<td>9.40</td>
<td>6.6 s</td>
</tr>
<tr>
<td>$^{282}$12</td>
<td>1.5126</td>
<td>9.74</td>
<td>0.69 s</td>
</tr>
<tr>
<td>$^{281}$12</td>
<td>1.5324</td>
<td>9.88</td>
<td>0.28 s</td>
</tr>
<tr>
<td>$^{280}$12</td>
<td>1.5494</td>
<td>10.02</td>
<td>0.12 s</td>
</tr>
</tbody>
</table>

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

References