# $\alpha$-decay Half-lives Study of Superheavy Nuclei

R. K. Paira[1],* B. B. Sahu[2], and B. Sahu[1]

[1] *Department of Physics, North Orissa University, Baripada-757003, INDIA and*
[2] *Department of Physics, School of Applied Sciences,*
*Kalinga Institute of Industrial Technology (KIIT) University, Bhubaneswar-751024, INDIA*

## Introduction

Now a days, the synthesis of superheavy nuclei (SHN) has become an outstanding research topic in nuclear physics. Since the predictions of the existance of superheavy island in 1960s. In recent years, much experimental progress has been made in synthesizing SHN with atomic number Z=114-118 by hot fusion reactions. $\alpha$-decay is the most powerful tool in studying exotic nuclei in the superheavy region as it can provide some reliable knowledge on the nuclear structure and is used to identify new isotopes when an unknown parent nucleus decays to a known daughter nucleus. In this paper, we calculate the $\alpha$-decay half-lives of some SHN by considering the unstable parent nucleus as a quantum two-body system of the ejected $\alpha$ particle and the daughter nucleus exhibiting resonance scattering phenomena under the combined effect of nuclear, coulomb and centrifugal forces. Finally, predictions within the same frame work are given for the $\alpha$-decay half-lives of nuclei having Z=120-126 are made for future experiments.

## Formulation

In the general decay law, the $\alpha$+nucleus system is considered as a Coulomb-nuclear potential scattering problem and the accurately determined resonance energy (E) of the quasibound state is taken as the Q-value of the decaying system [1, 2]. The width or life time of the resonance state accounts for the decay half-life. Th normalized regular solution u(r) of the modified Schrödinger equation is matched at radius r=R to the outside Coulomb Hankel outgoing spherical wave $f_C(kr) = G_l(\eta, kr) + iF_l(\eta, kr)$ such that

$$u(r) = N_0[G_l(\eta, kR) + iF_l(\eta, kR)], \quad (1)$$

where R is the radial position outside the range of the nuclear field.

For a typical $\alpha$-nucleus system with $\alpha$ particle as the projectile and the daughter nucleus as the target, let $\mu$ represent the reduced mass of the system and the wave number $k = \sqrt{\frac{2\mu}{\hbar^2}E}$ and $\eta$ stands for the Coulomb parameter $\eta = \mu\frac{Z_e Z_d e^2}{\hbar^2 k}$. With this the mean life $T$ (or width $\Gamma$) of the decay is expressed in terms of amplitude $N_0$ as

$$T = \frac{\hbar}{\Gamma} = \frac{\mu}{\hbar k}\ \frac{1}{\mid N_0 \mid^2}. \quad (2)$$

Since the wave function u(r) decreases rapidly with radius outside the daughter nucleus, it can be normalized by requiring that $\int_0^R \left|u_(r)\right|^2 dr = 1$. Further, using the fact that for a value of radial distance sufficiently large, the value of $G_l(\eta, kR)$ is very large as compared to $F_l(\eta, kR)$ by several order of magnitude, the $T$ of Eq. (2) is expressed as

$$T = \frac{\mu}{\hbar k}\frac{\mid G_l(\eta, kR) \mid^2}{P}, \quad (3)$$

where

$$P = \frac{\left|u(r)\right|^2}{\int_0^R \left|u_(r)\right|^2 dr}. \quad (4)$$

Result of the above expression gives values of mean life $T$ or half-life $T_{1/2}$=0.693 $T$ of the decay of the charged particle carrying angular momentum $l$ with Q-value equal to the resonance energy E. In this article, we simplify the formula (3) and put it in the well known linear form of GN law for the variation of log$T_{1/2}$ as a function of Q-value of the particle emitted with some amount of angular momentum $l$.

*Electronic address: `krishna.nou@gmail.com`

In the special case of Coulomb-nuclear problem, there are specific values of $\eta$ and $\rho = kR$ for which the Coulomb Hankel function $G_l$ can be expressed in some simple mathematical form giving quite accurate result. Using $2\eta > \rho$ with $l \geq 0$ [5], and after simplification we get the final formula[2] for $log_{10}T_{1/2}$ is given by

$$log_{10}T_{1/2} = a'\chi' + b'\rho' + c + d, \qquad (5)$$

$\chi' = Z_e Z_d\sqrt{\frac{A}{Q}}$, $\rho' = \sqrt{AZ_eZ_d(A_e^{1/3} + A_d^{1/3})}$, where $A=\frac{A_eA_d}{A_e+A_d}$. The constants $a'$, $b'$, c, and d are expressed as

$$a' = 2a_0e^2\sqrt{2m}/\hbar\ Ln10,$$
$$b' = -b_f\sqrt{2me^2r_0}/\hbar\ Ln10,$$
$$c = Ln\ c_f/Ln10,$$
$$d = -[\tfrac{2}{2\eta^2+1} + \tfrac{8}{2\eta^2+4} + ...+ \tfrac{2\ l^2}{2\eta^2+l^2}]/Ln10 + \text{Ln}\ M_l/Ln10,$$
$$b_f = 2 + a_0 - 2a_1 + (\tfrac{a_0}{4} + a_1 - 2a_2)t^{1/2} + (\tfrac{a_0}{8} + \tfrac{a_1}{4} + a_2 - 2a_3 - 1)t + (\tfrac{5}{64}a_0 + \tfrac{a_1}{8} + \tfrac{a_2}{4} + a_3)t^{3/2} + (\tfrac{5}{64}a_1 + \tfrac{a_2}{8} + \tfrac{a_3}{4} - \tfrac{1}{4})t^2 + (\tfrac{5}{64}a_2 + \tfrac{a_3}{8})t^{5/2} + (\tfrac{5}{64}a_3 - \tfrac{1}{8})t^3$$
$$c_f = [\tfrac{0.693}{3P}\sqrt{\tfrac{m}{2e^2}A(A_e^{1/3} + A_d^{1/3})r_0/Z_cZ_d}\ \ 10^{-23}]$$
$$t = \rho/2\eta < 1$$

$a_0 = 1.5707288$, $a_1 = -0.2121144$, $a_2 = 0.074240$, $a_3 = -0.018729$ [5],

$$\sqrt{M_l} = 1 + \frac{4(2l+1)^2-1}{16(2\eta\rho)^{1/2}} + \frac{[4(2l+1)^2-1](4(2l+1)^2-9]}{2[16(2\eta\rho)]^2} + \frac{[4(2l+1)^2-1][4(2l+1)^2-9][4(2l+1)^2-25]}{6[16(2\eta\rho)]^3}.$$

nucleon mass m= 931.5 MeV, square of electronic charge $e^2$=1.4398 MeV fm, $\hbar$= 197.329 Mev fm, and radial distance parameter $r_0 = 1.25$ fm.

We use $R = r_0(A_e^{1/3} + A_d^{1/3})$ as the touching distance over which the nuclear force is effective and $P = 10^{-3}$ taken from the properties of resonant wave function for all types of $\alpha$+daughter nuclei.

## Results and discussions

We have studied the $\alpha$-decay half-lives of several SHN by general decay law. The calculated results, $T_{1/2}^{form}$ (shown in Table-I) are in a good agreement with experimental data. In Table-II we present the predicted $\alpha$-decay half-lives of some SHN by using theoretical Q-values that are yet to be measured.

TABLE I: Comparison of experimental values of $\alpha$-decay half-lives and results of present calculation obtained by using formula (5)

| $^{A}_{Z}$ | $Q_\alpha^{expt}$(MeV) | $l$ | $T_{1/2}^{expt}$ | $T_{1/2}$[3] | $T_{1/2}^{form}$ |
|---|---|---|---|---|---|
| $^{294}_{118}$ | 11.81 | 0 | $0.69^{+0.64}_{-0.22}$ ms | 0.69 ms | 0.52 ms |
| $^{294}_{117}$ | 10.96 | 3 | $50^{+60}_{-18}$ ms | 135 ms | 56.16 ms |
| $^{293}_{116}$ | 10.67 | 1 | $61^{+57}_{-20}$ ms | 134 ms | 69.42 ms |
| $^{290}_{116}$ | 11.00 | 0 | $8.3^{+3.5}_{-1.9}$ ms | 13.1 ms | 10.38 ms |
| $^{289}_{115}$ | 10.34 | 2 | $0.38^{+0.18}_{-0.10}$ s | 0.62 s | 0.36 s |
| $^{288}_{115}$ | 10.61 | 3 | $87^{+105}_{-30}$ ms | 240 ms | 122 ms |
| $^{287}_{114}$ | 10.16 | 1 | $0.48^{+0.16}_{-0.09}$ s | 0.67 s | 0.41 s |
| $^{286}_{114}$ | 10.33 | 0 | $0.12^{+0.04}_{-0.02}$ s | 0.15 s | 0.13 s |

TABLE II: Predicted $\alpha$-decay half-lives of some unmeasured superheavy nuclei

| $^{A}_{Z}$ | $Q_\alpha^{theo}$(MeV) | $l$ | $T_{1/2}$[4] | $T_{1/2}$[3] | $T_{1/2}^{form}$ |
|---|---|---|---|---|---|
| $^{295}_{118}$ | 11.699 | 3 | 1 ms | 4.02 ms | 2.15 ms |
| $^{297}_{119}$ | 12.303 | 6 | - | 3.75 ms | 1.51 ms |
| $^{298}_{119}$ | 12.586 | 6 | - | 1.19 ms | 0.40 ms |
| $^{298}_{120}$ | 12.900 | 0 | 30 $\mu$s | 13.6 $\mu$s | 10.63 $\mu$s |
| $^{299}_{120}$ | 13.185 | 4 | 50 $\mu$s | 22.70 $\mu$s | 13.16 $\mu$s |
| $^{302}_{121}$ | 13.518 | 7 | - | 0.18 ms | 47.17 $\mu$s |
| $^{302}_{122}$ | 14.262 | 0 | - | 0.153 $\mu$s | 0.13 $\mu$s |
| $^{310}_{126}$ | 16.205 | 0 | - | 1.40 ns | 1.30 ns |

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