Study of Fusion, Resonance and Decay in Heavy Ion Collision

Swagatika Bhoi[1*] and Basudeb Sahu[2]
[1]*School of Physics, Sambalpur University, Jyoti Vihar, Burla-768019, INDIA and*
[2]*North Orissa Uniersity, Odisha-757003, INDIA*

Introduction

Alpha radioactivity and prediction of alpha decay half-lives have been widely studied experimentally as well as theoretically. In our work, we update and microscopically determine the parameters of Viola-Seaborg relation for α-decay half-lives. We study the emission process of α particles from an isolated quasi-bound state generated by an effective potential to a scattering state. An analytical expression for half-life is obtained in terms of Coulomb function, wave function and the potential. We then derive a closed-form expression for the decay half-life in terms of the parameters of the potential, Q-value of the system, mass and proton numbers of the nuclei and the formula is valid for light, medium, heavy and superheavy nuclei [1].

We also stress on nuclear radial independence by taking Frahn form of potential and by using the same closed form expression we trace the radial independence region where decay time is almost constant and predict the half-lives of a series of nuclei including half-lives of isotopes of nuclei with Z=119 and 120 [2].

In another work, we construct a potential particularly the nuclear part such that the combined potential of nuclear, electrostatic and centrifugal part is able to explain and account for the processes of scattering, decay and fusion in an α-nucleus interaction in unision [3].

*Electronic address: swagatikabhoi66@gmail.com

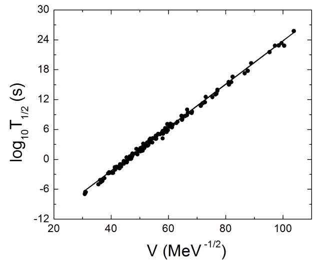

FIG. 1: Plot of $log_{10}T_{1/2}$ as a function of V=aχ+c (Eqn. 1) for α-decays in $l = 0$ state from decaying nuclei with Z=54-118 [1].

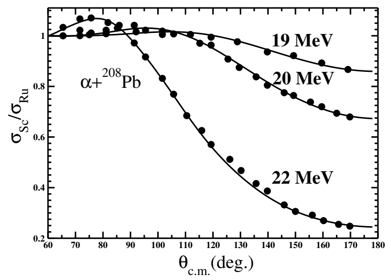

FIG. 2: Angular variation of the elastic scattering cross section at different incident energies [3].

Formalism

The closed form expression[1] for logarithm of decay half-life found microscopically is expressed as

$$logT_{1/2} = a\chi + c + d + b_l, \qquad (1)$$

where, $a = 1.4398\pi\sqrt{2(931.5)}/197.329 = 0.9889$,

$\chi = Z_\alpha Z_D\sqrt{\frac{A_\alpha A_D}{(A_\alpha+A_D)\ Q_\alpha}}$, Q_α represent the α-decay energy, Z_α, Z_D, A_α, A_D are

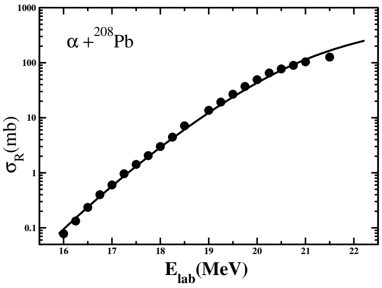

FIG. 3: Fusion cross section as a function of center of mass energy $E_{c.m.}$ [3].

the proton and mass numbers of the α particle and the daughter nucleus respectively. $c = -2logS$, $d = -2logD$, $S = c_f x_m R G_l \left(\frac{A_\alpha A_D \sqrt{Z_\alpha Z_D}}{A_\alpha + A_D}\right)$ $c_f = 0.22$, $x_m = 70, d = -45.2631$, R is the radial distance, $b_l = log(q_l), q_l = \frac{2\eta(2l+1)}{P_l(\eta)\rho^{2l}}$, Coulomb wave function $F_l(r) = C_l \rho^{l+1} G_l$, $C_l^2 = \frac{P_l(\eta)}{2\eta} \frac{C_0^2(\eta)}{(2l+1)}$, $P_l(\eta) = \frac{2\eta(1+\eta^2)(4+\eta^2).....(l^2+\eta^2)2^{2l}}{(2l+1)[(2l)!]^2}$.

Also, by using the Frahn form of potential[2] and incorporating the above closed form of expression of half-life, we have found radial independence of α-decay half-lives for a series of nuclei.

In another work, the potential developed for the nuclear part[3] is expressed as

$$V_N^R(r) = -V_0 \frac{1 + \delta\ exp[-(r/R_v)^2]}{\{1 + exp[(r - R_s)/2a_s]\}^2}, \quad (2)$$

$$V_N^I(r) = -\frac{W_0}{\{1 + exp[(r - R_I)/2a_I]\}^2}. \quad (3)$$

The radii R_v, R_s and R_I are expressed as $R_v = r_v(A_1^{1/3} + A_2^{1/3})$, $R_s = r_s(A_1^{1/3} + A_2^{1/3})$, and $R_I = r_I(A_1^{1/3} + A_2^{1/3})$. In optical model calculation the parameters, V_0=22 MeV, r_v=0.66 fm, r_s=1.27 fm, r_I=1.29 fm, a_s=0.62 fm, δ=3.5, W_0=5 MeV, a_I=0.28 fm for 19 MeV. Combining this potential with the usual Coulomb potential and the centrifugal potential, we solve the Schrodinger equation and explain different processes in α+nucleus system. We apply the formulation to the α+ $^{208}_{82}$Pb system for the explanation of the elastic scattering cross sections, fusion cross sections and the decay rate of particle from the parent $^{212}_{84}$Po nucleus.

Results

By using the closed form expression (Eqn. 1), we have predicted the half-lives of many nuclei and the plot of $log_{10}T_{1/2}^{pred}$ as a function of V=aχ + c shows a stright line for the case of l=0 as shown in Fig. 1. Considering the poles of S matrix and the potential in (Eqn.2 and 3) we describe decay rate elastic scattering cross section and fusion cross section as shown in TABLE I, FIG.2 and FIG.3.

TABLE I: Comparision of experimental results of α-decay half-life $log_{10}T_{1/2}^{exp}$ with the calculated results $log_{10}T_{1/2}^{OMP}$ obtained from poles of S matrix, S_l, and $log_{10}T_{1/2}^{anal}$ from poles of analytical S matrix S(k) [3].

Decay	Q_α (MeV)	$log_{10}T_{1/2}^{exp}$ (s)	$log_{10}T_{1/2}^{OMP}$ (s)	$log_{10}T_{1/2}^{anal}$ (s)
^{218}Po→^{214}Pb	6.115	2.27	2.36	2.28
^{216}Po→^{212}Pb	6.906	-0.84	-0.75	-0.89
^{214}Po→^{210}Pb	7.833	-3.38	-3.71	-3.97
^{212}Po→^{208}Pb	8.954	-6.52	-6.68	-6.52
^{210}Po→^{206}Pb	5.407	7.08	6.83	6.40
^{208}Po→^{204}Pb	5.215	7.96	7.96	7.47
^{206}Po→^{202}Pb	5.327	7.14	6.97	6.88
^{204}Po→^{200}Pb	5.485	6.28	6.14	6.05
^{202}Po→^{198}Pb	5.701	5.15	5.06	4.96
^{200}Po→^{196}Pb	5.981	3.74	3.74	3.64

Conclusion

We microscopically obtain an expression having updated parameters of Viola-Seaborg relation for α-decay half-lives and also showed radial independence for prediction of half-lives. Moreover, our constructed potential succesfully explain decay, elastic and fusion cross section in unison.

References

[1] Basudeb Sahu and Swagatika Bhoi, Phys. Rev. **C 93**, 044301 (2016).

[2] Swagatika Bhoi and Basudeb Sahu, Int. J. Mod. Phys. **27**, 1850048 (2018).

[3] Basudeb Sahu and Swagatika Bhoi, Phys. Rev. **C 96**, 044602 (2017).