STUDY OF SUPERHEAVY NUCLEI VIA A-DECAY.

Dr.Shweta Prakash
Department of Physics
Ajay Kumar Garg Engineering College
27thKm Stone, Delhi-Meerut Expressway, Ghaziabad, Uttar Pradesh-201009, India

Abstract – Superheavy Nuclei has been studied using the α-decay mode. The half-life values of the superheavy nuclei for α-decay mode has been calculated using the analytically solvable potential. In the analytically solvable potential, by variation of just one parameter, the best result for the half-life values has been obtained. The results are compared with experimental values available. The variation of the half-life values with Q-values has also been studied. It has been observed that for a fixed value of Z, as the Q-values increase, the Half-life values decrease. Lastly, an empirical formula has been developed and used to obtain the half-life values for α-decay mode for the super heavy nuclei. It is found that the half-life values compare well with experimental values. The range of superheavy elements for which the half-lives has been calculated is Z = 106 – 116. A graph has been plotted between half-life values of the mentioned superheavy elements against the Q-values.The island of stability near Z = 114 has also been located in this graph.

(Keywords: Superheavy elements, α-Decay, Half-life, decay mode, Q-values, range)

1.INTRODUCTION

There have been major advances in the experimental techniques in the recent time. This has made it possible to discover decent number of superheavy elements. In almost all the discoveries of superheavy nuclei fusion process has been used. Isotoptes of superheavy elements 112, 114, 116 have been produced by fusion-evaporation techniques. In this technique, 233, ^{238}U, ^{242}Pu,^{248}Cm and ^{249}Cf targets are irradiated with^{48}Ca beam at various energies. The excitation energy is kept low. The other experimental research shows that the superheavyheavy elements, with proton number Z = 107 – 112 have been synthesized at GSI, Darmstadt[1], while isotopes of the above mentioned elements followed by elements with Z = 114 – 116 and 118 have been synthesized at JINR-FLNR, Dubna[2]. Identification of a single isotope of Z = 113 was done at RIKEN, Japan[3]. The above mentioned researches showed that in superheavy elements, the dominant decay mode is α-decay mode. Based on these experimental researches, several theoretical studies started. This included, developing potential models, testing models, calculation of half-life values, excitation energies, and other properties. In all these approaches, the α-emission has been considered as a two-body quantum process between the daughter and parent nuclei. The α-particle interacts with the potential consisting of nuclear potential plus Coulomb potential. In this interaction the α-particle tries to penetrate through this potential barrier. These attempts are defined as assault frequency. The possibility that the α-particle escapes through the barrier is calculated in terms of decay probability, which is the product of assault frequency and barrier penetrability. The barrier penetrability which is also known as transmission probability has been calculated by using the WKB approximation method in the previous work. In the present work, α-decay of superheavy nuclei is considered as type of asymmetric fission. The exact expression for transmission probability has been used. In the next section, the potential model is mentioned.

2.POTENTIAL MODEL

In the present work we have studied the decay of 19 superheavy nuclei by emitting alpha-particle ranging from Z = 107 to Z = 116. As already mentioned above, the α -particle interacts with the potential consisting of nuclear and Coulomb potential. The nuclear potential has a dominant role when the α-particle is inside the nucleus. When the α-particle reaches the surface, it mainly faces a large Coulomb barrier. Thus, the α-particle in order to escape, has to cross an asymmetric barrier, consisting of a thin inner part and a long range broad outer part. In the present work, this asymmetric potential barrier is built by combining two symmetric potentials. The narrow inner potential where the separation between the α-particle and daughter nucleus is smaller than barrier radius R_B. The long range outer potential, where the separation between the α-particle and daughter nucleus is greater than the barrier radius R_B. The barrier radius R_B is actually the touching radius, where the parent and the daughter nuclei touch each other.

$$R_B = C_1 + C_2, \quad C_i = R_i - \frac{r_0^2}{R_i}, \qquad r_0 = 0.99 \text{ fm}, \quad i = 1, 2, \qquad R_i = 1.13A^{1/3}$$

C_i,'s , are the Susmann central radii. For the potential barrier, we have used a potential developed by Sahu et.al[6]. We have used this potential earlier also to study the half-life of proton-rich nuclei through proton emission [7]. This is an analytically solvable potential and is given as

$$V(r) = V_{01} [\lambda_1^2\nu_1(\nu_1+1) (1-y_1^2)+ (1-\lambda_1^2)/4 [5(1-\lambda_1^2)y_1^4-(7-\lambda_1^2)y_1^2+2](1-y_1^2)] + V_{02}[\lambda_2^2\nu_2(\nu_2+1)(1-y_2^2) + (1-\lambda_2^2)/4 [5(1-\lambda_2^2)y_2^4-(7-\lambda_2^2)y_2^2+2](1-y_2^2)] \quad (1)$$

This first term shows the inner potential and second shows the outer potential. The inner potential shows the formation of alpha particle inside the nucleus and the outer potential shows the separation of nucleus and alpha particle. In the equation (1), V_{01} and V_{02} are the strengths of potential in MeV. Parameters λ and ν are the dimensionless parameters. λ, is responsible for the shape of the potential and ν represents the range of the potential. The parameters λ, ν, V_{01} correspond to the inner potential. The parameters λ_2, ν_2, V_{02} correspond to the outer potential. The range of y_1 and y_2 are from -1 to 1. The parameters λ_1, ν_1, V_{01} are kept constant and small values so that the inner barrier is small and narrow, as compared to the outer barrier. The parameter ν_2 has been varied to obtain the best fit to the experimental value of alpha decay half-life of superheavy nuclei. It is to be mentioned here that potential consisting of dimensionless parameters λ and ν was first constructed by Ginnochio [8].The half-life is calculated as

$$t_{1/2} = \log_e 2/\Gamma \quad (2)$$

Γ is the rate of radioactive decay. It is given as $\Gamma = \Gamma_o T_p$. Γ_o is the frequency, by which the alpha particle is continuously hitting the potential barrier. This frequency has been calculated using the zero point vibration energy $E_v = ½\, h\, \Gamma_o$. The transmission coefficient is represented by T_p. The expression for T_p is the same which we have used in our previous work. It is written as

$$T = \frac{16\pi\lambda^4\lambda_1\lambda_1 h_1 h_2}{[(\lambda_2^2|L_1|^2 + \lambda_1^2|L_2|^2)(s_1^2 + h_1^2)(s_2^2 + h_2^2) + 8\lambda^4\lambda_1\lambda_2(s_1 s_2 + h_1 h_2)]}$$

$S_1 = \sin(\pi\bar{\upsilon}_1)$, $s_2 = \sin(\pi\bar{\upsilon}_2)$, $h_1 = \sinh\left(\frac{\pi k_1}{\pi_1^2}\right)$

$h_2 = \sinh\left(\frac{\pi k_2}{\pi_2^2}\right)$, $k_1 = \sqrt{\frac{Q}{V01}}$, $k_2 = \sqrt{\frac{Q}{V02}}$

$$\bar{\upsilon}_1 = [\frac{1}{4} - \bar{\upsilon}_{1(}\bar{\upsilon}_{1+1)} + \frac{\lambda_{1\,-1}^2}{\lambda_1^4} k_1^2]^{1/2} - 1/2$$

$$\bar{\upsilon}_2 = [\frac{1}{4} - \bar{\upsilon}_{2(}\bar{\upsilon}_{2+1)} + \frac{\lambda_{2-1}^2}{\lambda_2^4} k_2^2]^{1/2} - ½,$$

2.1MODEL PARAMETERS

The parameters defining our potential are mainly λ, ν, V_0 . The inner potential has parameters as λ_1, ν_1, V_{01} where as the outer potential has parameters λ_2, ν_2, V_{02}. The parameter λ represents the flatness or the upper curved part of the potential. In the previous studies it has been found the potential for the superheavy nuclei is only slightly curved at the top. In view of this, we have chosen the value of $\lambda_1 = 1.13$ for inner potential and $\lambda_2 = 1$ for outer potential. The parameter ν decides the range of the potential if the barrier strength V_B is fixed

$$V_B = V_{01}\left[\lambda_1^2\left(\nu_1^2 + \nu_1 + \frac{1}{2}\right) + \frac{1}{2}\right] = V_{02}[\lambda_2^2\left(\nu_2^2 + \nu_2 + \frac{1}{2}\right) + \frac{1}{2}]$$

The range parameter for inner potential is, $\nu1 = 0.3016$. It shows that the inner potential is narrow and short ranged The range parameter for outer potential $\nu2$ is adjusted to the best fit with the experimental result. The barrier height V_B has been calculated by the above mentioned relation, and is 27.607MeV nearly, for almost all the nuclei studied here.

3.RESULTS

The half-life values for 25 superheavy nuclei using analytically solvable has been calculated, with proton number Z ranging from 106 to 116. The half-life values have been calculated by varying just one parameter of the potential. The value of range parameter ν_2 which gives the best result falls within 14 -15. The table.1 shows the results of half-life values. The assault frequency, Q-values, experimental results are also shown in the table. It can be observed that since the exact expression for the transmission coefficient has used, the calculated values are in close agreement with the experimental results. In the present work, the $\log(T_{1/2})$ has been plotted with $(Q)^{-1/2}$ values and shown in figure1. In An empirical law has also been generated for this range of nuclei. The results are shown in Table2.

$$\text{Log}(T_{1/2}) = -66.016 + 1.8375Z/\sqrt{Q} \quad (3)$$

It is found that this empirical formula works quite well for the superheavy nuclei in the above mentioned range, with very small deviations. The relation between the half-life values and proton number has also been studied, in figure2. In the figure, it has been observed that the half-life values are large for Z =106, 112, and 114. This indicate a possibility of shell closure for these values of proton number Z. The predicted island of stability at Z = 114, can also be seen in the figure.

Table 1: Half-life values of Super heavy Nuclei

Nucleus(^{A}Z)	Q(MeV)	Γ_0(x $10^{21}s^{-1}$)	ν_2	Our work	Expt. Value[3]
^{271}106	8.67	0.379	16.531	114.9s	1.9min(+2.4) (-0.6)
^{266}107	9.26	0.343	15.783	2.468s	2.47s
^{272} 107	9.15	0.339	16.08	9.801	9.8(+11.7) (-3.5)
^{275}108	9.44	0.413	15.266	0.191	0.19(+0.22) (-0.07)
^{270}109	10.23	0.379	14.585	7.1ms	7.16ms
^{275}109	10.48	0.487	14.898	9ms	9.7(+46) (-4.4)ms
^{276}109	9.85	0.365	15.677	0.719	0.72(+0.87) (-0.25)s
^{279}110	9.84	0.431	15.38	0.201	0.20(+0.05) (-0.04)
^{278}113	11.90	0.441	14.397	343.8us	344us
^{291}116	10.89	0.545	15.0	18ms	18(+22) (-6)ms
^{285} 112	9.29	0.407	16.338	34s	34s(+17) (-9)
^{283} 112	9.67	0.4234	15.964	3.8127s	3.8(+1.2) (-0.7)
^{280} 111	9.87	0.3654	16.014	3.602s	3.6(+4.3) (-1.3)
^{289} 114	9.96	0.4361	15.942	2.707s	2.7(+1.4) (-0.7)
^{288} 114	10.09	0.509	15.737	0.8095s	0.8(+0.32) (-0.18)
^{284} 113	10.15	0.3758	15.581	0.4814	0.48(+0.16) (-0.09)
^{287} 114	10.16	0.445	15.601	0.4804s	0.48(+0.16) (-0.09)
^{283} 113	10.26	0.476	15.3	0.1029s	100(+490) (-45)ms
^{286} 114	10.33	0.521	15.38	0.1306s	0.13s(+0.04) (-0.02)
^{279} 111	10.52	0.4885	15.575	170.3ms	170(+810) (-80)
^{288} 115	10.61	0.393	15.282	87ms	87(+105) (-30)
^{287} 115	10.74	0.4987	15.14	32ms	32ms(+155) (-14)
^{292} 116	10.80	0.5448	15.02	18.4ms	18ms(+16) (-6)
^{290} 116	11.0	0.5549	14.85	7.1ms	7.1ms(+3.2) (-1.7)
^{274} 111	11.36	0.421	15.095	9.2ms	9.26ms

Table 2:Nuclei with the proton number Z = 111 – 116, Q-values and half-life values

Nucleus (Z)	Q (MeV)	Log($T_{1/2}$) (Calc.)	Log($T_{1/2}$) (exp.)
111	9.87	-1.156	0.557
111	10.52	-3.196	-0.769
111	11.36	-5.439	-2.036
112	9.29	1.468	1.53
112	9.67	0.0458	0.581
113	10.15	-0.8178	-0.317
113	10.26	-1.233	-0.988
114	9.96	0.388	0.432
114	10.09	-0.0314	-0.092
114	10.16	-0.241	-0.3184
114	10.33	-.0869	-0.884
115	10.61	-1.143	-1.060
115	10.74	-1.354	-1.495
116	10.80	-1.154	-1.735
116	11	-1.773	-2.149

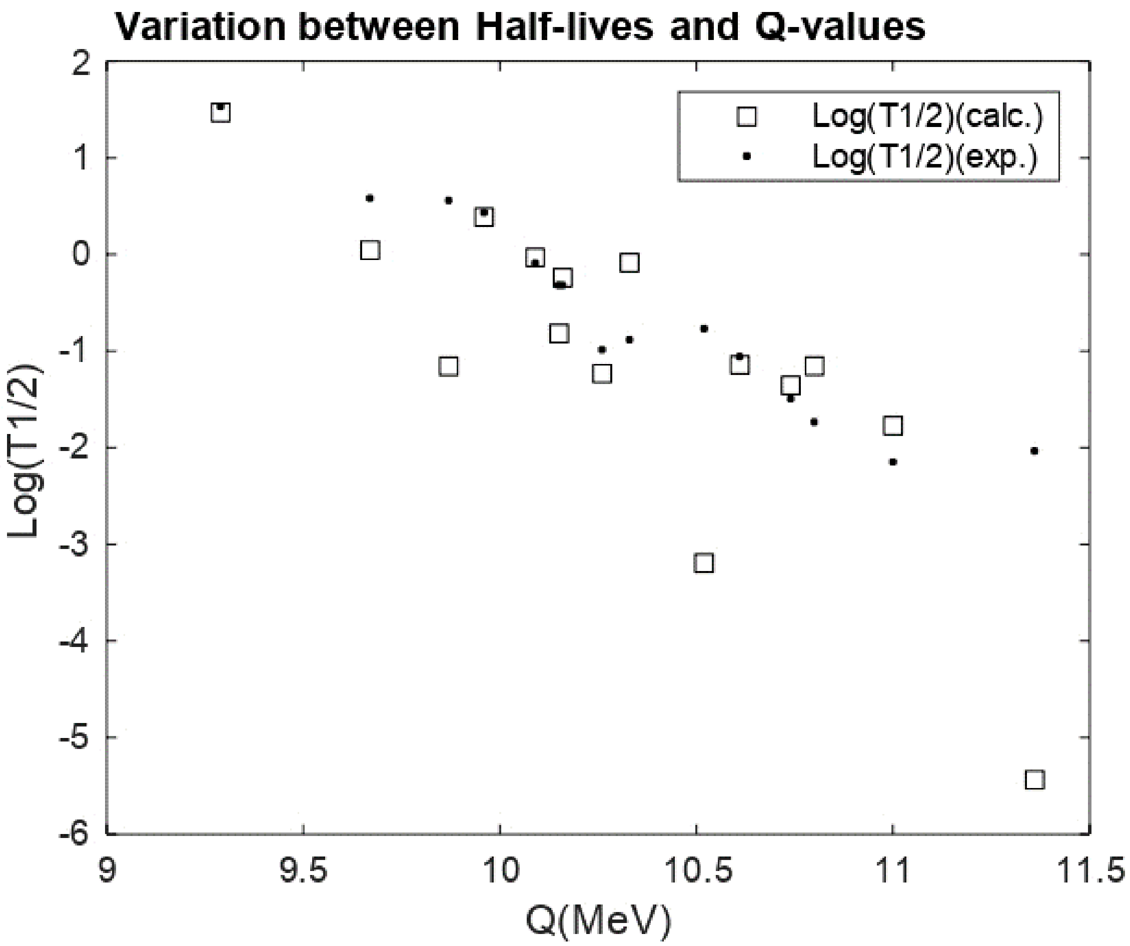

Figure 1: Variation of half-life values and Q-value

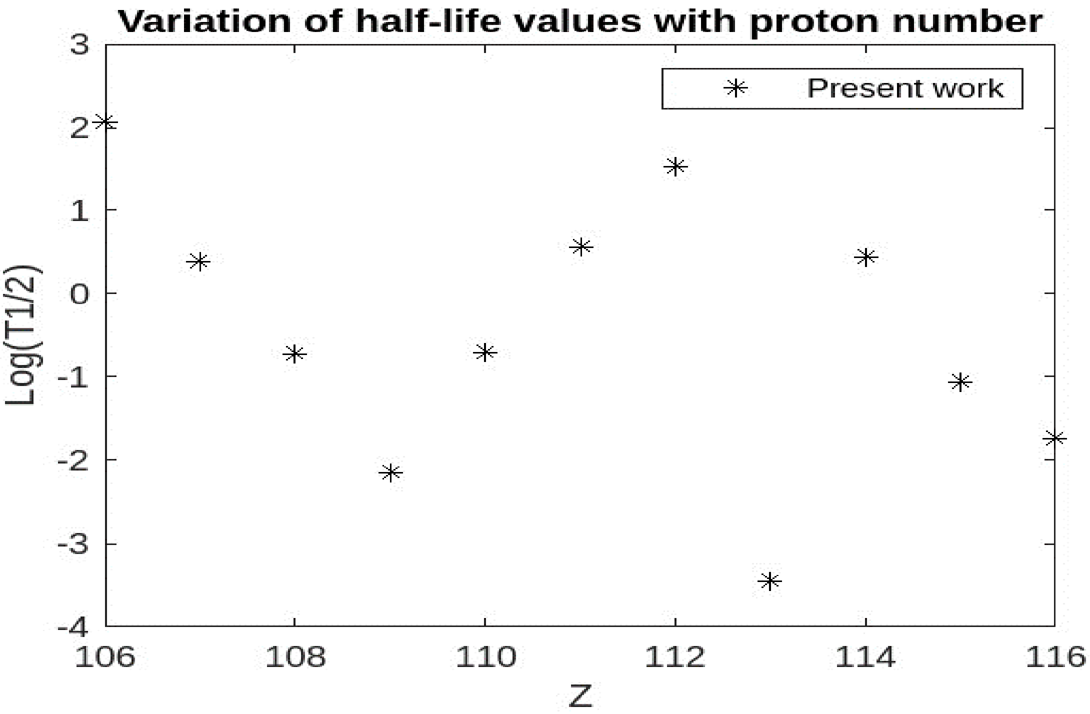

Figure2.: Plot between half-life($T_{1/2}$) values and proton number Z

4.CONCLUSION

The work can further be extended to study more superheavy nuclei. For future work, we can apply this potential for other decay processes also, such as two-proton radioactivity. The empirical formula can be developed for two-proton radioactivity. More study regarding the dimensionless parameters, that is shape parameter λ and range parameter ν can be done. The small deviations in the empirical formula can be modified.

REFERENCES

[1] . Chowdhury P.R, Samanta C and Basu D. N (2006) Phys.Rev.C73, 014612

[2]. Hofmann S et.al, (2004) Nucl. Phys.A734, 93

[3]. Morita K et.al, (2004) J.Phys. Soc. Jpn.73,259.

[4]. Oganessian Yu. Ts et.al., (2006) Phys. Rev.C 74, 044602.

[5] Dong J.M, Zang H.F and Royer G., (2009) Phys.Rev.C79, 054330.

[6] Sahu B., Sahu B., and Agarwalla S.K., (2008) Evaluation of eigenvalues of a smooth potential via Schroedinger transmission across multi-step potential, PRAMANA, Journal of Physics Indian Academy of Sciences Vol. 70, No. 1, pp. 27–39

[7] Mehrotra I, and Prakash S., (2008) Proton Radioactivity with Analytically Solvable Potential, , Pramana-Journal of Physics, 70, February, pp. 101-111.

[8] Ginocchio J.N., (1984) Ann. Phys. 152, 203.

Copyright & License: