Structural study of Es isotopes from α-decay modes

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Introduction

Alpha decay is one of the conspicuous decay modes exhibited by atomic nucleus in ground state and long lived isomeric heavy and super heavy regions of nuclei. Alpha decay provides us the knowledge about the existence of shell and sub shell closure in parent as well as daughter nuclei. Hence it plays a very important role in describing the structural properties as well as decay modes of a given nucleus. It is explained by quantum mechanical tunneling and the probability of alpha particle emission is related to the decay Q-value. We have calculated the Q-values from the binding energies of the nuclei. The binding energies are calculated using NL3*[1] as well as NL-SH [2] force parameters within an axially deformed relativistic mean field model (RMF) [3, 4]. With this calculated Q-values we examine alpha decay half-life of isotopic series of Es within the mass number 240≤ A ≤ 269 using two empirical formulas that is Modified Viola-Seaborg-Sobiczewski (VSM) formula [5] and Modified Royer formula (RM) [5] .

The significance of smaller value of half-life of a parent nucleus is that a shell stabilized daughter nucleus will be resulted from α-decay but a longer half-life indicates a shell stabilized parent nucleus against α-decay.

Formulation

We use our calculated Q-values to calculate the $\mathrm{Log_{10}T_{1/2}}(\alpha)$. For that we substitute the Q-values in the formulas given below. The formula of VSM [5] is

$$\log_{10}T_{1/2}(\alpha) = \frac{aZ+b}{\sqrt{Q_\alpha}} + cZ + d \qquad \text{(i)}$$

Where Z is the atomic number of the parent nuclei and the values of a, b, c and d are obtained from experimental fitting. Similarly the Modified Royer formula [5] is

$$\log_{10}T_{1/2}(\alpha) = a + bA^{1/6}Z^{1/2} + \frac{c.Z}{\sqrt{Q_\alpha}} \qquad \text{(ii)}$$

Where Z and A are the atomic number and mass number of parent nuclei and a, b and c are some constant values obtained from experimental fitting.

And the starting point of our Q-value calculation is the relativistic Lagrangian density for many body system [3, 4] as;

$$\begin{aligned} L = &\bar{\psi_i}(i\gamma^\mu\delta_\mu - M)\psi_i + \frac{1}{2}\delta^\mu\sigma\delta_{mu}\sigma - \frac{1}{2}m_\sigma^2\sigma^2(1) \\ &-\frac{1}{3}g_2\sigma^3 - \frac{1}{4}g_3\sigma^4 - g_s\bar{\psi_i}\psi_i\sigma - \frac{1}{4}\Omega^{\mu\nu}\Omega_{\mu\nu} \\ &+\frac{1}{2}m_\omega^2V^\mu V_\mu + \frac{1}{4}c_3(V_\mu V^\mu)^2 - g_\omega\bar{\psi_i}\gamma^\mu\psi_iV_\mu \\ &-\frac{1}{4}\vec{B}^{\mu\nu}.\vec{B}_{\mu\nu} + \frac{1}{2}m_\rho^2\vec{R}^\mu.\vec{R_\mu} - g_\rho\bar{\psi_i}\gamma^\mu\vec{\tau}\psi_i.\vec{R^\mu} \\ &-\frac{1}{4}F^{\mu\nu}F_{\mu\nu} - e\bar{\psi_i}\gamma^\mu\frac{(1-\tau_{3i})}{2}\psi_iA_\mu \end{aligned}$$

Result and discussion

We have calculated the $Log_{10}T_{1/2}(\alpha)$ values for $\mathrm{Es}_{99}^{240-269}$ isotopic series using our calculated Q-values both for NL3* and NL-SH force parameters and also using the available experimental Q-values from NNDC [6] in (i) and (ii). The variation of $\mathrm{Log_{10}T_{1/2}}(\alpha)$ with parent neutron number are plotted in two separate graphs. The variation for NL3* is shown in FIG-1 and for NL-SH, it is shown in FIG-2. In FIG-1 all the curves show similar nonlinear nature with peaks at odd neutron numbers signifying greater stability of parent nuclei against α-decay. But FIG-2 shows, a sharp peak at N=154 both for VSS (NLSH) and Royer (NLSH) curve i.e Es^{253} isotope shows a greater stability against α-decay and shell closure for neutron of parent nuclei. Except the exception at N=154 all peaks are observed for odd N nuclei similar to that of parent nuclei.

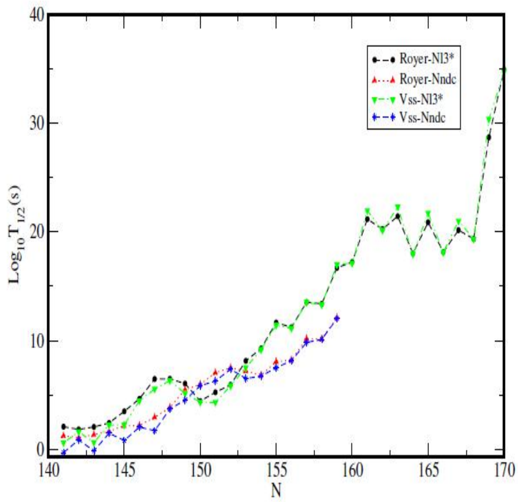

FIG-1 Plot of $\mathrm{Log_{10}T_{1/2}(\alpha)}$ of Es isotopes as function of parent neutron number (N).

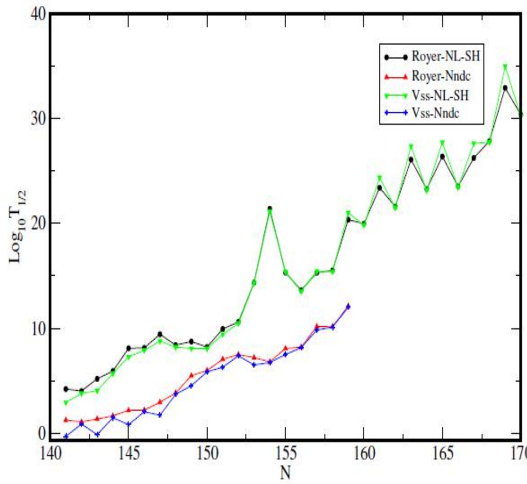

FIG-2 Plot of $Log_{10}\,T_{1/2}\,(\alpha)$ of Es isotopes as function of parent neutron number (N).

Conclusions

RMF theory is successful in explaining alpha decay from ground and isomeric state; We have calculated the Q-values using NL3* and NLSH force parameters in RMF model. Using these calculated Q-values in VSM and in modified Royer formula we obtain $\mathrm{Log_{10}T_{1/2}(\alpha)}$ values and compare the values with calculated $\mathrm{Log_{10}T_{1/2}(\alpha)}$ values using available experimental Q-values using the above empirical formulas. We find at N=154 the parent nuclei shows a greater stability against α-decay which can be seen as a sharp peak in VSS (NLSH) and Royer (NLSH) curve in FIG-2. The most calculated half-lives, irrespective of ground state to ground state are in good agreement with the experimental data shown in Fig.1 and 2. Here we restrict the study on decay of Es nuclei from ground state of parent nuclei to ground states of daughter nucleus. The crank behaviour of odd-even nuclei may be due to microscopic properties of nuclear structure, nevertheless the shell structure of the parent and daughter nuclei, influences the alpha decay probability. Although the interplay of angular hindrance and nuclear structure hindrance cannot be ignored. The present study reveals that the relativistic mean field theory successfully explain the α-decay modes of Es isotopes, and also could explicate even for even-even, even-odd and odd-even nuclei.

References

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