Favored and unfavored alpha transitions from the ground state and isomeric state

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Introduction

Alpha decay was observed by Rutherford [1], a century ago. It was interpreted as a consequence of quantum penetration of α-particle in 1928 by Gamow and later on independently by Gurney and Condon. Usually α-decay takes place between ground states having same angular momentum and parity. But now with the progress in technology, nuclei in exited states having relatively large life span (isomeric states) are experimentally possible. So favored and unfavored α-decay of such excited states is relevant for theoretical studies.

In this paper we have performed a systematic study on isomeric state α-decay using the recently proposed Coulomb and proximity potential model for deformed nuclei (CPPMDN) [2]. In this model, the CPPM (Coulomb and proximity potential model) [3] is modified by incorporating the first and second order deformation values of both the parent and daughter nucleus, and treating the third particle as spherical.

Coulomb and Proximity Potential Model for Deformed Nuclei (CPPMDN)

The Coulomb interaction between the two deformed and oriented nuclei is given as,

$$V_C = \frac{Z_1Z_2e^2}{r} + 3Z_1Z_2e^2 \sum_{\lambda,i=1,2} \frac{1}{2\lambda+1}\frac{R_{0i}^{\lambda}}{r^{\lambda+1}} Y_{\lambda}^{(0)}(\alpha_i)\left[\beta_{\lambda i} + \frac{4}{7}\beta_{\lambda i}^2 Y_{\lambda}^{(0)}(\alpha_i)\delta_{\lambda,2}\right]$$

with

$$R_i(\alpha_i) = R_{0i}\left[1+\sum_{\lambda}\beta_{\lambda i}Y_{\lambda}^{0}(\alpha_i)\right]$$

Here $R_{0i} = 1.28A_i^{1/3} - 0.76 + 0.8A_i^{-1/3}$ where α_i is the angle between the radius vector and symmetry axis of the i[th] nuclei. The two-term proximity potential for interaction between a deformed and spherical nucleus is given by Baltz et. al., [4] as

$$V_{P2}(R,\theta) = 2\pi\left[\frac{R_1(\alpha)R_C}{R_1(\alpha)+R_C+S}\right]^{1/2}\left[\frac{R_2(\alpha)R_C}{R_2(\alpha)+R_C+S}\right]^{1/2}$$

$$\left[\left[\varepsilon_0(S) + \frac{R_1(\alpha)+R_C}{2R_1(\alpha)R_C}\varepsilon_1(S)\right]\left[\varepsilon_0(S) + \frac{R_2(\alpha)+R_C}{2R_2(\alpha)R_C}\varepsilon_1(S)\right]\right]^{1/2}$$

Here $R_1(\alpha)$ and $R_2(\alpha)$ are the principal radii of curvature of the daughter nuclei at the point where polar angle is α , S is the distance between the surfaces along the straight line connecting the fragments, R_C is the radius of the spherical cluster, $\varepsilon_0(S)$ and $\varepsilon_1(S)$ are the one dimensional slab-on-slab function. Using one dimensional WKB approximation, the barrier penetrability P is given as

$$P = \exp\left\{-\frac{2}{\hbar}\int_a^b \sqrt{2\mu(V-Q)}\,dz\right\}$$

The turning points "a" and "b" are determined from the equation, V(a)=V(b)=Q. The half life time is given by

$$T_{1/2} = \left(\frac{\ln 2}{\lambda}\right) = \left(\frac{\ln 2}{\upsilon P}\right)$$

where, $\nu=(\omega/2\pi)=(2E_v/h)$, represents the number of assaults on the barrier per second and λ the decay constant. E_v, is the empirical vibration energy.

Results and discussion

Using the CPPMDN we have calculated α-decay half-life values for favored and unfavored transitions of nuclei in mid Z and heavy region. It encompasses the study on favored α-decay in the region 67 ≤ Z ≤ 91. In this study we mainly concentrate on four types of α-decay transitions: (i) ground states to ground states (g.s.→g.s.), (ii) ground states to isomeric states (g.s.→i.s.), (iii) isomeric states to ground states (i.s.→g.s.) and (iv) isomeric states to isomeric states (i.s.→i.s.). Fig.1 shows the comparison between calculated and the experimental values.

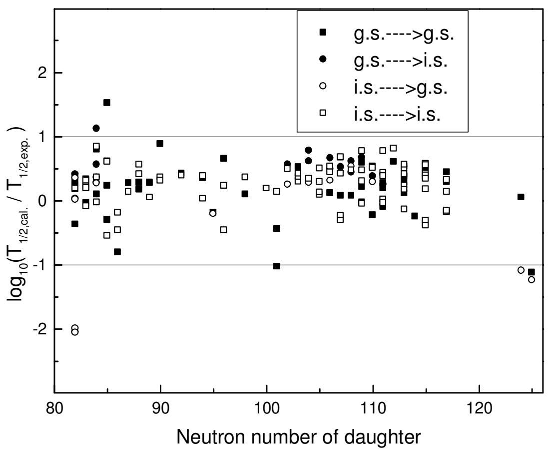

Fig. 1. Comparison calculated $T_{1/2}$ values with the corresponding experimental data.

We have drawn a plot with $Q^{-1/2}$ against $\log T_{1/2}$ for all favored decay by using the calculated $T_{1/2}$ and experimental Q values. The resulting plot is shown in Fig.2. From this figure it is clear that, for all favored transitions, the decay between both the ground states and isomeric states follow Geiger-Nuttal law.

On this ground, we have performed a study on unfavored α-decay by plotting Geiger-Nuttal plot, as similar to favored decay. Fig.3 represents the G-N plot of $\log_{10}T_{1/2}$ versus $Q^{-1/2}$ for favored and unfavored α emission for various Bi isotopes. From the figure it is clear that for both favored and unfavored decays, points occur on two straight lines satisfying the Geiger-Nuttal law and in most of the transitions, the calculated values are in close agreement with the experimental data.

In the case of ^{186}Bi the experimental half-life lie on the G-N curve for unfavored one but the computed value ($T_{1/2}$= 1.37x10^{-3}, ℓ =1) lies on GN plot for favored one. We have recalculated $T_{1/2}$ with ℓ=5 and the computed value coincides with the corresponding experimental data. So in our study it is clear that the angular momentum possessed by the α-particle may be 5 instead of 1 and we like to draw the attention of both experimentalists and theoreticians regarding this matter.

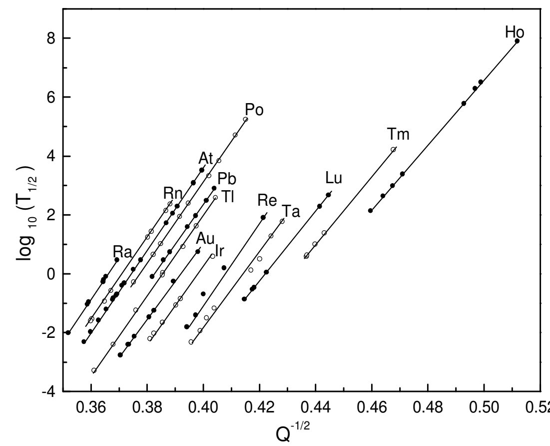

Fig.2. Geiger- Nuttal plot of favored alpha decay transitions.

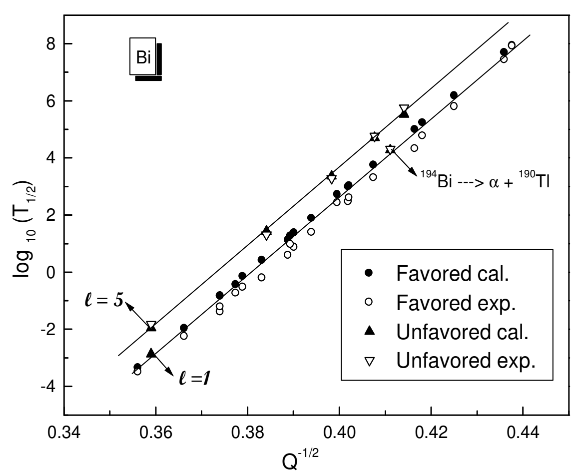

Fig.3. Geiger- Nuttal plot corresponding to calculated and experimental data of favored and unfavored transitions of Bi isotopes.

References

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