Alpha decays of heavy nuclei to ground and excited states of daughter

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Introduction

A century ago Rutherford observed α-decay for the first time and from then on α-decay has been one of the most important and widely discussed topics of nuclear physics. Alpha decay can provide some reliable knowledge on nuclear structure and is used to identify new isotopes via the observation of α-decay from unknown parent nucleus to a known daughter nucleus. The α-decay theory was formulated by Gamow and independently by Gurney and Condon in 1928 on the basis of quantum tunneling.

The fine structure of α-decay was observed for the first time in 1929 by Rosenblum [1] in Orsay. In recent years fine structure studies in α-decay has increased – especially the studies (both theoretical and experimental) of two kinds of alpha transitions of even-even nuclei i.e, the α-decay to excited 0^+ states and to members of ground state rotational band. In this paper we have studied the α-decay of even-even nuclei from ground state to ground state and ground state to excited states of daughter nuclei within the Coulomb and Proximity Potential model [2] which has been modified by incorporating the ground-state deformations β_2 and β_4 of the parent and daughter but treating the cluster as a sphere.

Results and discussion

The Coulomb and proximity potential model for deformed nuclei (CPPMDN) is applied to the α - decay of even-even nuclei in the range $88 \le Z \le 102$ from ground state of the parent nucleus to the ground state and excited states of the daughter nucleus. The Q-value for the transition between ground states of parent and daughter nuclei is,

$$Q_{g.s \to g.s} = \Delta M - (\Delta M_1 + \Delta M_2) + k(Z^{\varepsilon} - Z_1^{\varepsilon}),$$

where, ΔM, ΔM_1 and ΔM_2 are the mass excess of parent, daughter and alpha nuclei. The term kZ^{ε} describes the effect of atomic electrons where k=8.7eV and ε = 2.517 for nuclei with Z ≥ 60 and k = 13.6eV and ε = 2.408 for nuclei with Z<60.

The Q-value for the α transition between the ground level of parent nucleus and the various levels of daughter nucleus with excitation energy E_i^* is,

$$Q = Q_{g.s \to g.s} + E_i^*$$

Figure 1 gives α decay scheme for ^{222}Ra parent to various levels of ^{218}Rn daughter.

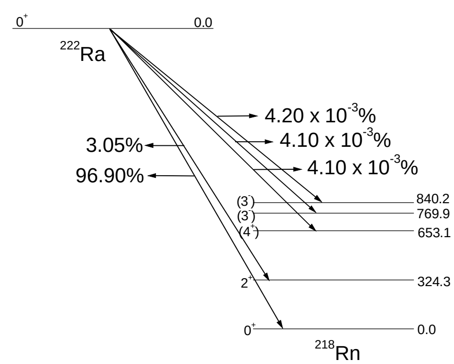

Fig. 1 Alpha decay scheme for ^{222}Ra parent to various levels of ^{218}Rn daughter.

We have computed α - decay half lives of even-even nuclei in the range 88 ≤ Z ≤ 102 from ground state of the parent nucleus to the ground state and excited states of the daughter nucleus taking quadrapole and hexadecapole deformation of parent and daughter treating alpha particle as spherical one. We have used the experimental deformation parameter values β_2 taken from Ref [3] and for the cases in which there are only theoretical ones we have taken them from Ref. [4]. On comparing our half life calculations with the experimental values a relatively good agreement between the two is obtained.

Once the α half lives are obtained we go on to determine the branching ratios of α decay to each state of the rotational band of the daughter nucleus with the help of the decay width which is defined as,

$$\Gamma(Q_i, \ell) = \hbar \nu P(Q_i, \ell),$$

where ν is the assault frequency and $P(Q_i, \ell)$ is the barrier penetration probability. The branching ratio of the α decay from the ground state of the parent nucleus to the level i of the daughter nucleus is determined as,

$$B_i = \frac{\Gamma(Q_i, \ell_i)}{\sum_n \Gamma(Q_n, \ell_n)} \times 100\%,$$

where the sum n is going over all states, which can be populated during the α transition from the ground state of the parent nucleus. On examining the branching ratio values it is seen that the highest branching ratios are to the 0^+ states followed by the 2^+ states. The α transitions to the remaining states are strongly hindered.

The hindrance factor (HF) for the transitions to the different states is simply a ratio between calculated (theoretical) and measured (experimental) decay constant or the ratio between experimental half life and theoretical half life and is given by

$$HF = \frac{\lambda_{theor.}}{\lambda_{\exp.}} = \frac{T_{1/2}^{\exp.}}{T_{1/2}^{theor.}}$$

The lowest value of the hindrance factor is obtained for the $0^+ \rightarrow 0^+$ transitions. As we move to the higher excited states the hindrance factor increases. The top layer of figure 3 is showing the histogram of hindrance factor for transitions to various states of ^{222}Ra, ^{252}Cf and ^{252}Fm nuclei and the bottom layer gives the histogram of branching ratio for the same nuclei. From these figures it can be seen that the hindrance factor increases while branching ratio decreases as we go from the ground state to ground state transitions to the ground state to excited state transitions.

We have also evaluated the standard deviation of the half lives as well as of the branching ratios. The standard deviation is estimated using the following expression,

$$\sigma = \left\{ \frac{1}{(n-1)} \sum_{i=1}^{n} \left[\log\left(\frac{T_i^{theor.}}{T^{\exp.}} \right) \right]^2 \right\}^{1/2}$$

The computed standard deviation of the half lives for all transitions is 0.86 while the same calculated using data from Denisov et al. [5] is 1.48. The estimated standard deviation for the branching ratio values is 1.09. On evaluating the standard deviation of the branching ratios to the various states separately it is found that the standard deviation for the ground state to ground state transition is only 0.05 and it increases as we move to the higher excited states which are due to the effect of nuclear structure.

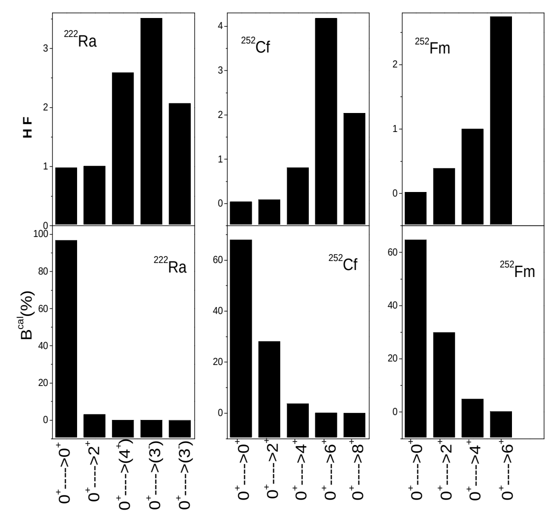

Fig. 2. Histogram showing hindrance factor and branching ratio of ^{222}Ra, ^{252}Cf and ^{252}Fm nuclei.

References

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