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Alpha and cluster decay half-lives in Tungsten isotopes: A microscopic analysis

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Abstract

Alpha and cluster decay half-lives for Tungsten (W) isotopes in the range between 2p drip line and beta stability line are studied. The sensitivity of different Skyrme parametrizations in predicting the alpha decay and probable cluster decay modes from W isotopes have been analysed. The half-lives are calculated using Universal Decay Law (UDL). Predicted half-lives are compared with Effective Liquid Drop Model (ELDM) and also with available experimental values. The use of harmonic oscillator (HO) and transformed harmonic oscillator (THO) basis do not produce much differences in the results. The study also revealed the role of neutron shell closure in cluster decay process.

Keywords: Cluster; Q-value; Half-life; Hartree–Fock–Bogoliubov

1. Introduction

Cluster radioactivity is defined as the spontaneous emission of a fragment, heavier than alpha particle and lighter than the lightest fission fragment, from the parent nuclei, without being accompanied by neutron emission [1–5]. This phenomenon was first predicted by Sandulescu et al. in 1980 [6]. This exotic decay was later experimentally observed by Rose and Jones [7] in 1984, with the emission of ^{14}C cluster from ^{223}Ra. Cluster radioactivity is a cold nuclear phenomenon, explained based on quantum mechanical fragmentation theory (QMFT) [8–12]. One of the dom-

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inant decay modes in nuclei is the α-decay, which is the emission of ${}^{4}_{2}$He from the parent nuclei. The probability of formation of a cluster is mainly determined by its binding energy. This implies that of all the possible cluster emissions, α-cluster is the most prominent one.

Many theoretical models have been developed to study the phenomenon of cluster radioactivity. The widely used phenomenological models are Preformed Cluster Model (PCM) [10,13–16] and Unified Fission Model (UFM) [4,17]. In PCM, the cluster is assumed to be preformed inside the parent nucleus and the preformation probability has to be found out explicitly. In UFM, the parent nucleus undergoes continuous dynamical changes through a molecular phase and finally disintegrates into a daughter and a cluster. Here the preformation probability is taken as unity. Several theoretical and experimental studies on cluster decay have been carried out in recent years. Different studies show that this phenomenon occurs in those regions where daughter nuclei should either be doubly magic or in its vicinity.

In our previous work, we have analysed the different decay modes in Osmium (Os) isotopes using Hartree–Fock–Bogoliubov (HFB) theory [18]. In the present work, we made an attempt to study the feasibility of alpha and cluster decay from Tungsten (W) isotopes in a systematic way with the help of Skyrme HFB theory. Many works, both theoretical and experimental, have been devoted to the study of alpha decay from various W nuclei in recent years [19–21]. Cluster radioactivity mainly falls in two regions, trans-tin and trans-lead. Nuclei in the rare-earth region ($150 < A < 190$) are good candidates where this process is observed to occur, i.e., in the trans-tin region or its vicinity. In our quest for finding various cluster decay modes among different rare-earth nuclei, in which W falls, we devoted this work to analyse the feasibility of cluster decay modes in W isotopes. Moreover, W, which belong to the transitional region, is a deformed nucleus and can be expected to exhibit some heavy decay modes [3].

The paper is organised as follows. In sec. 2, a brief account of the microscopic theory (HFB theory) which is used for the present study is given. In sec. 3 we have shown the details of our calculations. Results and discussion are given in sec. 4, where we have presented the main part of the study. In sec. 5, the conclusion drawn from the present work is given.

2. Hartree–Fock–Bogoliubov theory

A brief description of the Hartree–Fock–Bogoliubov theory is given below. The many body Hamiltonian expressed in terms of annihilation and creation operators is given by [22],

$$H = \Sigma_{ij} t_{ij} a_i^{\dagger} a_j + \frac{1}{4} \Sigma_{ijkl} V_{ijkl} a_i^{\dagger} a_j^{\dagger} a_k a_l \tag{1}$$

A set of quasiparticle state is used as the trial wave function. The bare particles are transformed to quasiparticles by using Bogoliubov transformation [22]:

$$\beta_k^{\dagger} = \Sigma_l U_{lk} a_l^{\dagger} + V_{lk} a_l \tag{2}$$

$$\beta_k = \Sigma_l V_{lk}^{*} a_l + U_{lk}^{*} a_l^{\dagger} \tag{3}$$

In terms of the density matrix ρ and the pairing tensor κ, on which the wavefunction Φ depends, the Hartree–Fock–Bogoliubov energy can be expressed as

$$E[\rho, \kappa] = \frac{< \Phi | H - \lambda N | \Phi >}{< \Phi | \Phi >} = Tr[(\varepsilon + \frac{1}{2}\Gamma)\rho] - \frac{1}{2} Tr[\Delta \kappa^{*}] \tag{4}$$

where Hartree Fock (HF) potential Γ and pairing potential Δ are defined as

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