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Decay properties of newly synthesized $^{207,208}Th$ isotopes

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1. Introduction

The ^{233,235}U and ^{239}Pu are the thermally fissile nuclei, which are used as the fuel in the Nuclear Energy generation in Nuclear Reactors. Out of these three isotopes, only ^{235}U is naturally available. In the last few years, Patra *et. al.* [1], predicted that some of the Thorium and Uranium neutron-rich isotopes can also be used as fuel in Nuclear Reactors for their thermally fissile nature. Mostly, the isotopes near/on the $\beta-$stability line undergo $\alpha-$decay. However, the neutron-deficient and neutron-rich isotopes undergo $\beta-$decay. Although ^{233,235}U are directly thermally fissile, but ^{233}U is not available in nature. To compensate for the deficiency, ^{232}Th can be converted to ^{233}U thermally fissile with the help of a neutron addition with two subsequent $\beta-$decay. Recently, Yang *et. al.* [2] have produced the new isotope ^{207}Th in the laboratory by taking the fusion reaction of $^{36}Ar+^{176}Hf$. So, it is interesting to study the decay properties, such as alpha decay energy (Q_α) for ^{207,208}Th. For, $\alpha-$decay, the (Q_α) is a crucial quantity, which is used to calculate the $\alpha-$decay half-life $T^{\alpha}_{1/2}$ with various proposed decay models. The recently developed effective field theory motivated relativistic mean field (E-RMF) based IOPB-I parameter set by Kumar *et. al.* [3] is used for this study.

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2. Theoritical formalism

The decay properties of a nucleus can be studied by noting the Q_α, which is defined as;

$$Q_\alpha(Z,N) = BE(Z,N) - BE(Z-2,N-2) - BE(2,2), \quad (1)$$

where the Q_α, BE(N, Z) and BE(N −2, Z −2) are referred to as the $Q-$value in alpha decay energy (in MeV), the BE of the parent nucleus (in MeV), and the BE of the daughter nucleus (in MeV) respectively. Again the BE of ^4He is denoted as BE(2, 2) which is numerically 28.296 MeV. The BE of the nuclei are obtained from the E-RMF model with IOPB-I parameter set. The detailed procedure can be found in Ref. [1].

3. Results and discussions

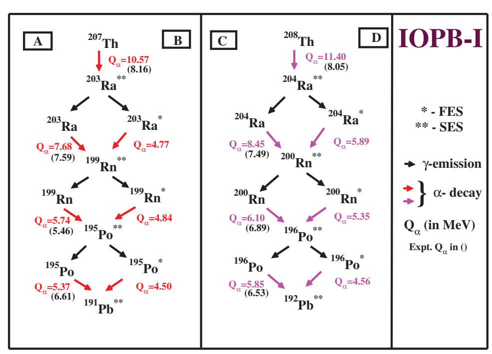

FIG. 1: The possible decay chains of $^{207,208}Th$ are presented along with the used notations.

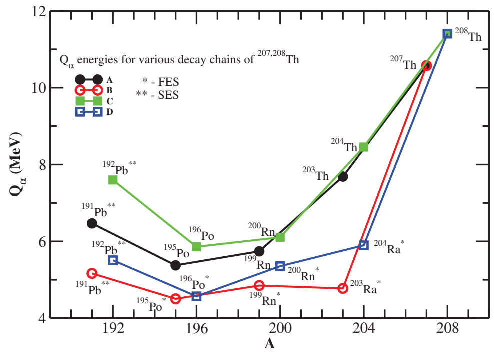

FIG. 2: The alpha decay energies (Q_α) of the possible $^{207,208}Th$ decay chains are presented as a function of mass number A. The A, B, C, and D decay chains in Fig. 1 can be viewed here.

In this present work, the effective field theory motivated relativistic mean field (E-RMF) formalism with IOPB-I parameter set is used to calculate the $Q-$values of the alpha decay energies for the $^{207,208}Th$ chains. To get the convergence solutions in this E-RMF model, we have taken the basis space for fermions and bosons as $N_F = 12$ and $N_B = 20$ respectively. The ground state (GS), first excited state (FES) and second excited state (SES) intrinsic binding energies are determined by taking various deformations as inputs. Then the decay chains for $^{207,208}Th$ are investigated. The two α decay chains have been observed for the recently produced $^{207,208}Th$ nuclei. Here, in Fig. 1, the GS ^{207}Th nucleus decays to the SES $^{203}Ra^{**}$. It is to be noted that the $\alpha-$decay does not permit always from the ground state to ground state. Many times, it has been noticed that the decay takes place from various intrinsic states. Also, it is observed that the nucleus waits for further $\alpha-$decay by releasing energy in the form of $\gamma-$decays to reach the ground state. In this way, the produced nucleus achieve various $\alpha-$decay chains. Further the mode of decay can be made through ground state (GS) and excited state (FES). The same is also seen for ^{208}Th nucleus. In Fig. 2, the plotted decay chains such as A, B, C, and D (in Fig. 1) are analysed. The chains almost follow the same trend. The experimental Q_α are shown in the parenthesis. From the comparison, it is noticed that the experimental data matches with the calculations relatively well.

4. Summary

The E-RMF based IOPB-I parameter set is used for the determination of the ground state, first excited state and second excited state binding energy by assuming different initial deformations. Then the alpha decay chains for both ^{207}Th and ^{208}Th nuclei are analysed. Four subsequent alpha-particles are emitted to reach the stable Pb nucleus as observed for both of the nuclei. The mode of decay can happen through channeling the ground state and the first excited state respectively. The alpha decay energies (Q_α) produced by the ground state nuclei are higher in magnitude as compared to the energies produced by the first excited states. More the value of Q_α, more the possibility of decay. Hence the decay chains made by the ground state nuclei are highly acceptable. The calculated $Q_\alpha-$values are comparable with the measured experimental data. Further studies regarding the half-lives $T^\alpha_{1/2}$ of the considered nuclei with the help of various models are under process. Again, the analysis of effects of symmetry energy (which is derived with the help of relativistic energy density functional) on the decay modes are under investigation, and will be communicated soon.

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