Alpha-decay energy (Q_α) landscape of heavy and superheavy nuclei

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Introduction

Alpha decay is identified as one of the most important decay modes of heavy and superheavy nuclei (SHN). The α-decay phenomenon by Gamow, and Condon and Gurney was one of the earliest applications of quantum mechanics to nuclear physics. In the Gamow's model, α-decay is treated as a quantum tunneling through the Coulomb barrier. In general, the calculation of half-life time T_α is important for two reasons: (i) formation of SHN is mainly identified by the detection of α-decay chains. From the detected decay signature, the nuclei formed by nuclear fusion can be deduced. (ii) α-decay can probe the shell structure and predict the magic numbers in the superheavy region. Further, the behavior of T_α and/or Q_α with proton and neutron numbers can be used to infer the stability regions in the nuclear chart.

SHN and their decay studies have received much attention in the past few decades. The stability of SHN is governed by the competition between α-decay and spontaneous fission. The lifetimes of both disintegration modes are important in predicting the isotopes. which are formed in the fusion reaction and it primarily depends on the Q-value. Small differences in the Q-values may lead to significant variation in the expected lifetimes and branching ratios.

The present study investigates the sensitivity of T_α and/or Q_α to the model used and assesses the correlation between the behavior of T_α and/or Q_α-values with the change of the proton and neutron numbers.

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Alpha-decay (Q_α) energy

The Q_α-values are calculated as follows:

$$Q_\alpha = \mathrm{BE}_\alpha + \mathrm{BE}_d - \mathrm{BE}_p, \quad (1)$$

where BE_α, BE_d, and BE_p are the binding energies of the α-particle, daughter nuclei, and parent nuclei, respectively. In this study, the binding energies of daughter and parent nuclei are deduced from the two different models namely WS4 [1] and FRDM2012 [2]. Further, the α-particle binding energy is fixed to its measured value ($\mathrm{BE}_\alpha = 27.273692$ MeV) [3].

Results and discussion

The calculated Q_α energies with the use of Eq. (1) are presented as a function of proton (Z_d) and neutron (N_d) numbers of the daughter nuclei in Figs. 1 and 2, for the nuclei (with $Z_p \geq 80$ and $N_p \geq 126$, and $Q_\alpha > 0$ MeV) listed in the WS4 and FRDM2012 mass tables, respectively. It is known that, for different isotopic α-decay chains, the variation of Q_α is found to linearly increasing with Z and irregularly decreasing with N. In Fig. 1 with the use of WS4 mass table, the $^{204-208}_{82}$Pb nuclei are stable against alpha-decay because all of its proton and/or neutron levels are filled. In both the Figs. 1 and 2, a deep and sharp minimum is found at $N_d = 126$ and a clear minimum exists at $N_d = 184$, and this confirms the presence of neutron shell closure effects. Also, there are other minima presented in both the figures due to two different mass models and marked them as dotted lines.

The variation of T_α for the proton and neutron numbers of the daughter nuclei will be studied and the results will be presented elsewhere.

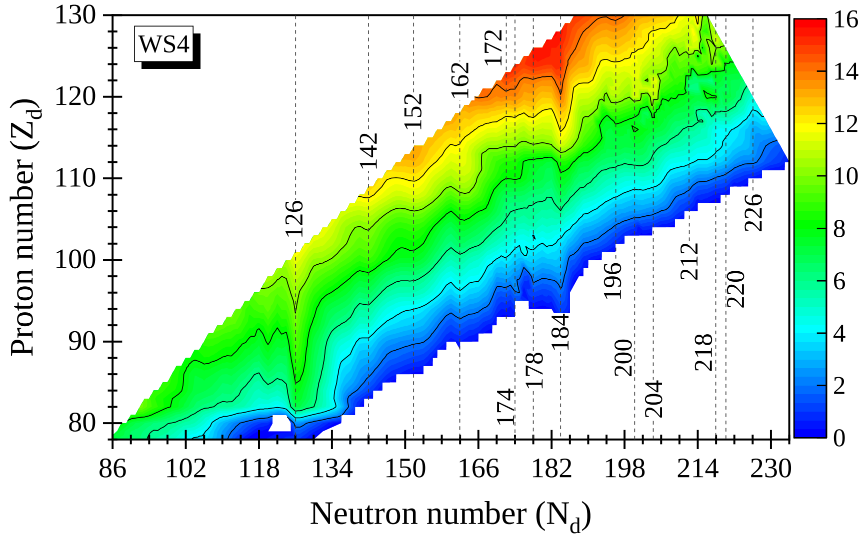

FIG. 1: The calculated Q_α energies as a function of proton and neutron numbers of the daughter nuclei. Here, the Q_α values are extracted from the WS4 mass table.

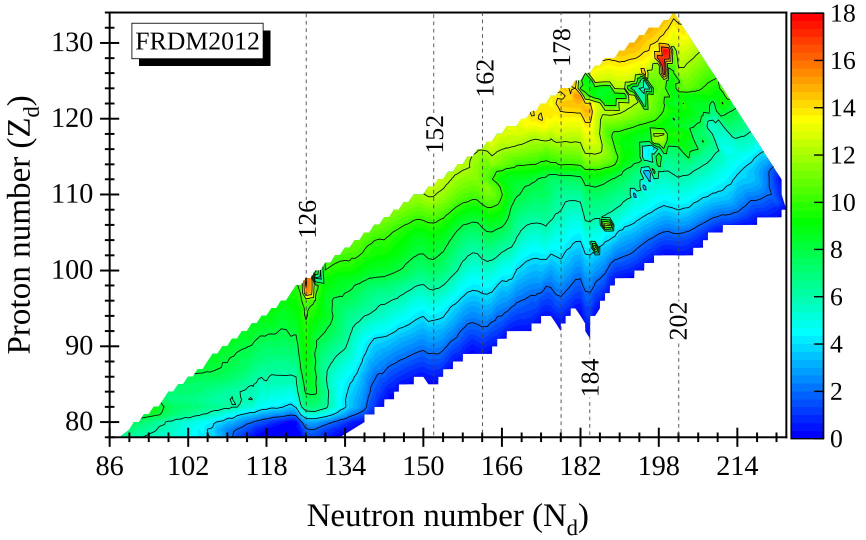

FIG. 2: Same as Fig. 1, but for the use of FRDM2012 mass table.

References

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