Decay properties of hyperheavy nuclei $Z = 164$

G. Naveya[1], S. Santhosh Kumar[2], and A. Stephen[1*]
[1] *Department of Nuclear Physics, University of Madras, Guindy Campus, Chennai-600025, INDIA and*
[2] *Department of Physics, Kanchi Mamunivar Centre for Post Graduate Studies, Lawspet, Puducherry-605008, U. T. of Puducherry, INDIA*

Introduction

The location of magic islands in the superheavy region is an open problem in modern nuclear physics, to address this, several theoretical and experimental works on superheavy nuclei (SHN) have been performed since 1960. The synthesis of SHN received a major attention, and hence the heaviest SHN artificially produced till now is Z = 118 [1]. In some astrophysical processes like supernova explosion and neutron star merger where neutron flux is in abundance, SHN may get formed, but there is no direct evidence of SHN. Optical lines of many actinide atoms and ions up to Einsteinium(Z = 99) have been detected in the spectra of the Przybylskis star [2] and the short lifetime of these isotopes give rise to a possibility that they were created in decay of longer half-life closed shell superheavy isotopes present in atmosphere [3]. In the OLIMPYIA project the charge distribution studies in olive crystal of meteorites had given evidence for three superheavy nuclei in the range $105 < Z < 130$, and further regression analysis had provided an accurate estimate of the Z of one of these nuclei to be 119^{+10}_{-6} with a probability of 95 percent [4]. All these findings are through theoretical studies of properties of SHN and their stability, hence theoretical half-life studies have considerable importance. In this work, we present a systematic study on decay properties of Z = 164 nucleus, which is expected to be the next proton magic number, around which a magic island of hyper-heavy element could occur, for which the magicity was predicted by us earlier [5].

*Electronic address: stephen_arum@hotmail.com

Methodology

Decay process is modelled here as a fission-like process. The post-scission region potential is $V_{ext}(r) = V_n(r) + V_c(r) + V_l(r)$. To describe the nuclear interaction between daughter and fragment, proximity formalism is taken, which is given by [6],

$$V_n(r) = 4\pi\gamma b \frac{C_1 C_2}{C_1 + C_2} \phi(s). \tag{1}$$

An appropriate form of pre-scission cubic potential is [7],

$$V_{ov}(r) = (-E_v + Q) + [V(r_t) + E_v - Q] \times \left[s_1 \left(\frac{r - r_i}{r_t - r_i} \right)^2 - s_2 \left(\frac{r - r_i}{r_t - r_i} \right)^3 \right]. \tag{2}$$

The details on various quantities which govern these potentials can be referred from Ref.[6–8]. The tunneling probability is calculated using improved transfer matrix method [9], where the potential barrier $V(r)$ is represented as multistep function,

$$V(r) = V_j = V \left[\frac{r_{j-1} + r_j}{2} \right], \tag{3}$$

where $r_{j-1} < r < r_j$; $j = 1, 2, ...N$. The wavefunction in barrier region is taken as plane waves and WKB wavefunctions are used at the boundaries. The complete formalism to obtain tunneling probability and the half-life is described in Ref.[8]. For the present study, we have used the DIRHB computer code which is a relativistic self-consistent mean-field framework code which solves the stationary relativistic Hartree-Bogoliubov equations [10]. Using DD-PC1 effective interaction the ground state properties of nuclei are obtained.

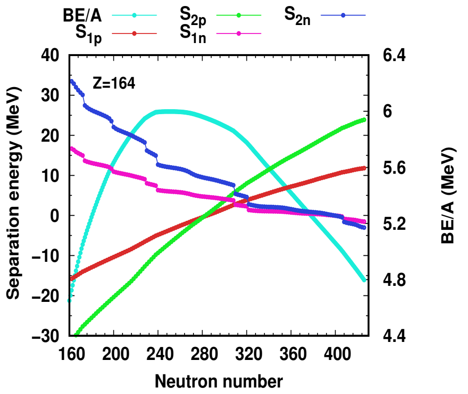

FIG. 1: The separation energy curve of 1proton, 1neutron, 2proton & 2neutron and BE/A for Z=164 isotopes are shown.

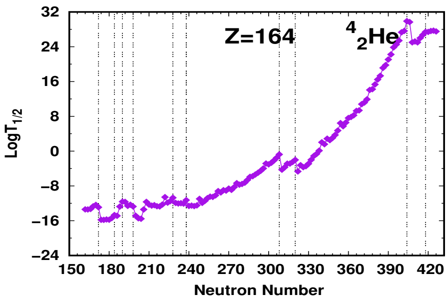

FIG. 2: The α-decay half-life of Z=164 isotopes.

Result and Discussion

The BE/A curve (fig. 1) reveals that isotopes with N = 240-260 are tightly bound due to high binding energy per nucleon value. This 1-proton, 1-neutron, 2-proton, and 2-neutron separation energy curves bring the isotopes which are prone to proton and neutron decay (the ones below $S_{p(n)} = 0$). The α-decay half-life presented in Fig. 2 consists of several peaks which suggest relative stability of the nuclide compared to neighbouring isotopes, which indicates the possible neutron magic/sub-magic numbers at N = 172, 184, 190, 198, 228, 238, 320, 404 & 420. In Fig. 3 the 1p, α and SF half-lives are shown. The lifetime with smaller $T_{1/2}$ dominates the other modes of decay. The proton decay is the dominant decay mode in the range $326 \leq A \leq 392$, and α-emission in $394 \leq A \leq 470$, and SF in $472 \leq A \leq 590$. The dashed lines correspond to the experimental detection limits $10^{-6}s \leq T_{1/2} \leq 10^{30}s$, and it encloses the decay modes of isotopes which are within experimental detection constraints. The crossing over of 1p and α decay suggests that the next neutron magic number beyond 184 will be around 228. These results may be highly useful in studying SHN traces in astrophysical and cosmic sources, and for upcoming terrestrial synthesis experiments.

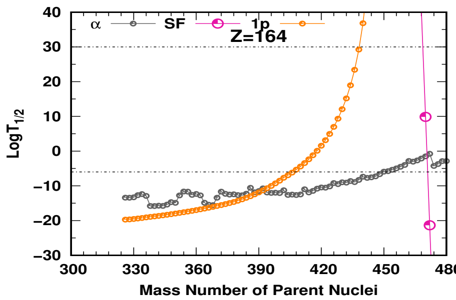

FIG. 3: Competition between different decay modes of Z=164 (the half-life of proton and SF is shown only to indicate the intersection with α-decay curve, full data is not shown).

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