Indian Journal of Pure & Applied Physics
Vol. 58, April 2020, pp. 304-307

Systematics of alpha decay hindrance factors in doubly-even nuclei

Sushil Kumar[a], Sukhjeet Singh[a*], Balraj Singh[b] & A K Jain[c]

[a]Department of Physics, Akal University, Talwandi Sabo 151302, India

[b]Department of Physics and Astronomy, McMaster University, Hamilton, Ontario L8S 4M1, Canada

[c]Department of Physics, Amity Institute of Nuclear Science and Technology, Noida 201 313, India

Received 17 February 2020

In present work, we have calculated the hindrance factors of 182 even-even alpha emitters using Preston's formulation of alpha decay probabilities and presented HFs systematics of 1^- and 3^- states in reflection asymmetric even-even quadruple-octupole deformed nuclides (A~216-230). The calculated HFs of both 1^- and 3^- states decrease with reduction in neutron number and this decrease is attributed to onset of intrinsic reflection asymmetry. There is a trend reversal for 1^- states at N=132 (^{218}Ra) and N=134 (^{220}Rn), which might be a possible indication of departure from static octupole deformation. Similarly, HFs systematics is discussed for $^{224\text{-}230}$Th and $^{232\text{-}236}$U isotopic chains along with 2^+ states observed in daughter nuclei in N=132-146 isotonic chains.

Keywords: Even-even alpha emitters, Hindrance factors, Reflection asymmetry

1 Introduction

Alpha hindrance factor (HF), the ratio of experimental to theoretical partial half–lives of alpha transitions, is found to be an important tool in extracting nuclear structure information[1-4]. Various theoretical techniques have been developed in order to understand the alpha–decay process and hence to calculate the penetrability of alpha particles through a barrier[1,5]. The alpha transitions for which HF lies between 1 and 4, called favored transitions and take place between nuclear states having similar configurations and hence it is promising to ascertain both J^π and nucleonic configurations assignments for a given daughter (parent) state if those of parent (daughter) are known[6]. Similarly, the alpha HFs quantifies the correlation between nuclear wave functions of the initial state of parent and final state of daughter nuclei; larger wave function's overlap gives a lower HF[3]. The systematics of alpha-decay HFs can be used to deduce a variety of quantities like total alpha branching ratio, intensities of unobserved alpha groups and excitation energy of level in daughter nucleus[6]. In the present study, the spin-independent part of Preston's equations[1] have been used for the calculations of alpha decay probabilities. This formalism contains radius of the daughter nuclide, r_0, as a free parameter. By setting HF=1 for the ground-state to ground-state alpha branch for an even-even nuclide[2], the radius parameter for the daughter nuclide can be deduced[7] that can be used to deduce alpha hindrance factors for alpha-fed excited states in even-even nuclides. We have calculated HFs of 182 even-even alpha emitters in the framework of Preston's formulation[1] by using ALPHAD_RadD program[8] and present the systematics of alpha HFs with daughter neutron number in reflection asymmetric (RA) mass region (A=216-230) i.e. for quadruple-octupole deformed nuclei. Additionally, the systematics of HFs for 2^+ states observed in N=132-146 isotonic chains is also presented

2 Methodology

In the present study, a well established Preston's spin-independent formulation[1] with only essential steps described here, has been used. In this formulation, a preformed alpha particle is considered to be moving inside a nucleus having rectangular potential field of depth of V_0; V_0 = constant for $r < r_0$, where r is the distance from the center of the product nucleus and r_0 is the radius of the product nucleus. The field beyond effective nuclear radius was assumed to be generated by a Coulomb potential ($2Ze^2/r$, where Z is the atomic number of product nucleus and e is the elementary charge) between alpha particle and daughter nucleus. The solution of the time dependent Schrodinger equation is assumed to have a form[1]:

*Corresponding author (E-mail: sukhjeet.dhindsa@gmail.com)

$u = \psi(x, y, z)\exp(-iEt/\hbar)$

The wave-function ψ should obey following boundary conditions (a) at $r = 0$ at ψ is finite, (b) at $r = r_0$, ψ and $d\psi/dr$ are continuous, (c) ψ represents as outgoing wave for $r > r_0$. The Schrödinger equation for alpha particle in afore said potential field can be written as:

$$\frac{d^2 X_l}{dr^2} + \frac{2m}{\hbar^2}\left[E - V - \frac{\hbar^2 l(l+1)}{2mr^2}\right] X_l = 0$$

where, $E = E_\alpha - \frac{1}{2} i\hbar\lambda$; E_α is the energy of α-particle and λ the time constant; are complex eigen values. In the interior of the nucleus with V=U, we have

$$X_l^i = \left\{\frac{2m(E-U)}{\hbar^2}\right\}^{\frac{1}{4}} r^{1/2} J_{l+\frac{1}{2}}\left(\left\{\frac{2m(E-U)}{\hbar^2}\right\}^{\frac{1}{2}} r\right)$$

where, J denotes Bessel functions and superscript i refer to interior of the nucleus. The solution X_l^i represents a standing wave and imaginary part of E related to the leak of alpha particle through the potential barrier.

3 Input Parameters

In the present work, the daughter radius parameter (r_0) is the main input used to calculate the HFs of alpha-fed excited states in even-even nuclides. In order to deduce r_0, a set of experimental quantities such as Q_α value, parent nuclide's half-life ($T_{1/2}$), total alpha–decay branching ratios (%α), and alpha intensities (I_α) are used. The Q_α energies are taken from recent atomic mass evaluation of M. Wang et al.[9], total alpha-decay branching ratios and half-lives of parent nuclides are taken from the ENSDF database[10] supplemented by recent data from literature.

In order to calculate HFs of various excited states, the recently developed ENSDF analysis code namely, ALPHAD_RadD[8], which is based on Preston's equations for alpha decay transition probabilities[1], has been used. This program can also be used to deduce HFs in odd-A and odd-odd nuclei by employing recently evaluated[7] list of even-even daughter radius parameters.

4 Results and Discussion

In Reflection Asymmetric even-even quadruple-octupole deformed nuclides (A~216-230), two separate bands with opposite parity i.e. I^π= 0^+, 2^+, 4^+… and I^π= 1^-, 3^-, 5^-… are generally observed[4]. In present paper, we studied the systematics of alpha HFs for 1^- and 3^- states with daughter neutron number in above said RA mass region (A~216-230). The results of HF systematics of 1^- and 3^- states observed in $^{218-226}$Ra isotopic chains with daughter neutron number are presented in Fig.1(a). From this figure, it is clear that, the HFs of both 1^- and 3^- states smoothly decreasing with reduction in neutron number. This decrease of HFs is attributed to onset of

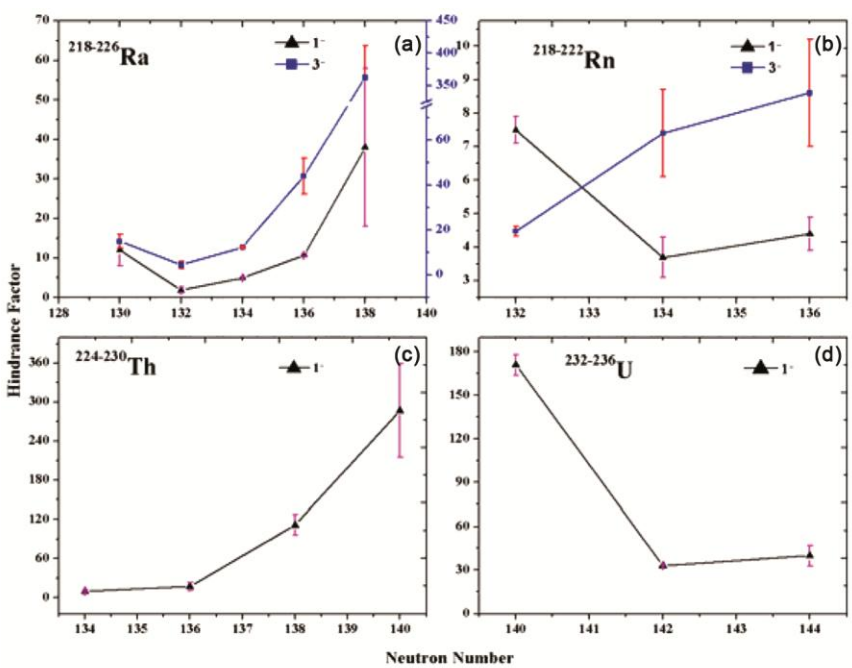

Fig. 1(a-d) — HF's systematics with daughter neutron number for $^{218-226}$Ra, $^{218-222}$Rn, $^{224-230}$Th and $^{232-236}$U nuclides.

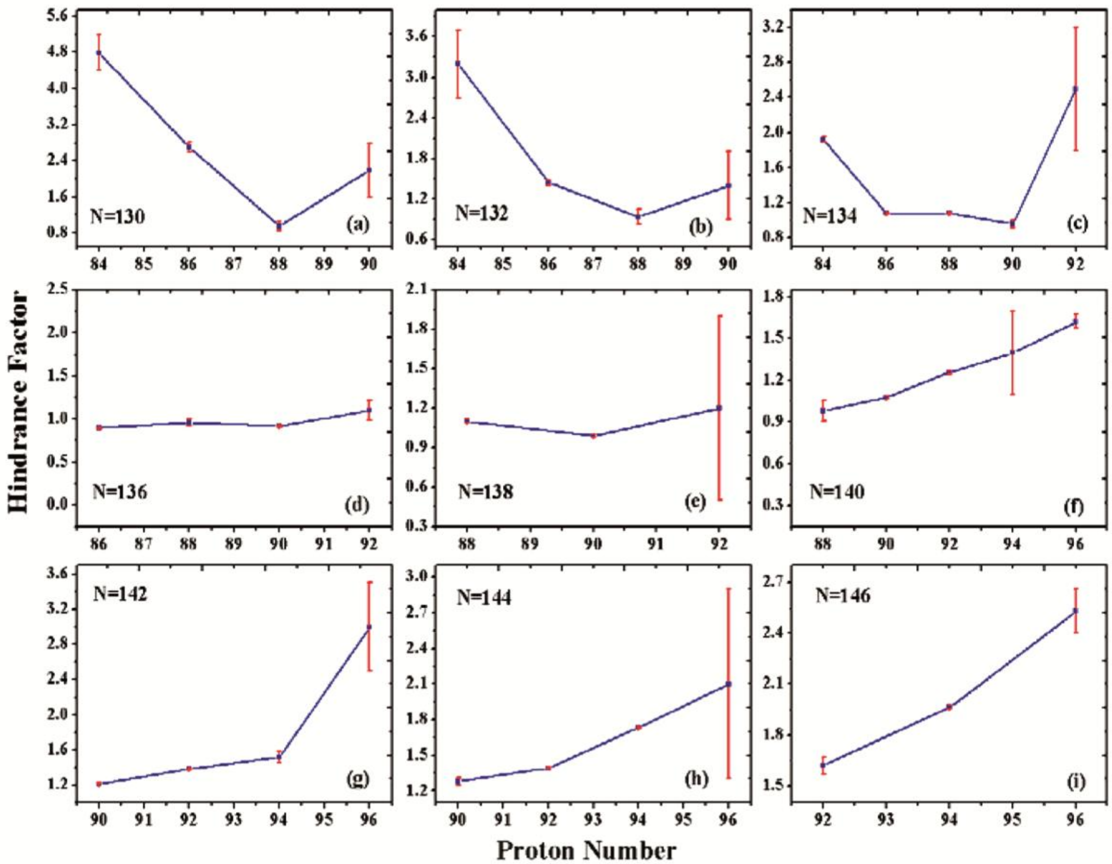

Fig. 2(a-i) — HF's systematics of 2^+ states observed in daughter nuclei in N=132-146 isotonic chains.

static Quadruple-Octupole deformation, but there is a trend reversal at N=132 (^{218}Ra), which might be a possible indication of departure from static Quadruple-Octupole deformation[3].

Similar trend reversal in HFs systematics of 1^- state at N = 134 is also observed for $^{218-222}$Rn nuclides (Fig.1 (b)), but such reversal could not be observed in $^{224-230}$Th (Fig.1(c)) as experimental data for 1^- state in lower mass region is not accessible. The HF systematics of 1^- state in $^{232-236}$U nuclides (Fig.1(d)) shows a minimum at N=142 and may be due to similar shape transition as discussed for Ra and Rn isotopic chains.

Additionally, we have also presented the systematics of HFs of 2^+ states observed in N=132-146 isotonic chains as shown in Fig. 2(a-i). From Fig. 2(a-c), a smooth decrease in HFs of 2^+ states with increase in proton number is observed till Z=88 in N=130, 132 and till Z=90 in N=134 isotopic chain. This smooth decrease in HFs indicates more probable alpha penetration through coulomb barrier and hence could be attributed to decrease in stability beyond Z=82 shell closure. The abrupt increase of HF at Z=90 in N=130, 132 and at Z=92 in N=134 isotopic chain is still an open problem. Although there is increase in HFs in other isotonic chains (N=136-146) as shown in Fig. 2(d-i), but minima corresponding to certain Z number could not be identified due to inaccessibility of experimental data for these isotonic chains. On the basis of above systematics (Fig. 2(a-i)), we suggest that all the experimentally observed alpha decays branches (0^+ to 2^+) are favored.

5 Conclusions

The HFs systematics of 1^- and 3^- states observed in RA mass region is presented. The HFs of both 1^- and 3^- states decrease with reduction in neutron number and this decrease of HFs could be attributed to onset of intrinsic reflection asymmetry, but there is a trend reversal for 1^- state at N=132 (^{218}Ra) and N=134 (^{220}Rn), which might be a possible indication of departure from static octupole deformation. A smooth decrease in HFs of 2^+ states with proton number is observed N=130, 132 and N=134 isotonic chains, which indicates the enhanced alpha penetration probability beyond Z=82 shell closure.

Acknowledgement

The financial support from DAE-BRNS, Govt. of India (Sanction No. 36(6)/14/60/2016-BRNS/ 36145) is gratefully acknowledged.

References

1 Preston M A, *Phys Rev*, 71 (1947) 865.
2 Akovali Y A, *Nucl Data Sheets*, 84 (1998) 1.
3 Parr E, Smith J F & Greenlees P T, *Phys Rev C*, 94 (2016) 014307.
4 Sheline R K & Bossinga B B, *Phys Rev C*, 44 (1991) 218.
5 Rasmussen J O, *Phys Rev*, 113 (1959) 1593.
6 Martin M A & Tuli J K, ENSDF Manual: Guidelines for Evaluators, (1988) 250.
7 Singh S, Kumar S, Singh B & Jain A K, *Nuclear Data Sheets*, (under review-2019).
8 ALPHAD_RadD, A program to calculate alpha hindrance factors and theoretical half-lives, Version 2d' (2019), available at www-nds.iaea.org/public/ensdf_pgm/.
9 Wang M, Audi G & Kondev F G, *Chin Phys C*, 41 (2016) 030003.
10 ENSDF database maintained by National Nuclear Data Center, BNL USA www.nndc.bnl.gov/ensdf/