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Theoretical studies on the α decay half-lives of hyper and normal isotopes of Po

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Abstract. The α decay half-lives of hyper and normal isotopes of Po nuclei are studied in the present work. The inclusion of Λ–N interaction changes the half-life for α decay. The theoretical predictions on the α decay half-lives of normal Po isotopes are compared with experimental results and are seen to be matching well with each other. The neutron shell closure at $N = 126$ is found to be the same for both normal and hypernuclei. The Geiger–Nuttal (G–N) law for α decay is unaltered in the case of hypernuclei. The hypernuclei will decay into normal nuclei by mesonic or non-mesonic decay modes. Since the half-lives of normal Po nuclei are well within the experimental limits, our theoretical results suggest experimental verification of the α emission from hyper Po nuclei in a cascade process.

Keywords. α decay; hyper nuclei; half-life.

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1. Introduction

The surveillance of the first nuclear fragments with a bound Λ hyperon has confirmed the existence of a third nuclear component in addition to protons and neutrons. Nuclear structures containing strange baryons, that is, hyperons are known as hypernuclei. The first hypernucleus was observed by Danysz and Pniewski in 1952, which is a boron nucleus, in which a neutron is replaced by a Λ^0 hyperon [1]. The importance of hypernuclear physics lies in understanding the elementary interactions that determine the properties of matter. So hypernuclear physics can be considered as the bridge between nuclear and particle physics.

During the last few decades, many hypernuclei have been produced experimentally and the studies on hypernuclei have received a lot of attention [2–4]. The advancements in the production and studies on hypernuclei are reviewed in refs [5–8]. Among the various hypernuclei, Λ hypernuclei are the most known and much studied nuclei [9]. Different properties of a nucleus such as nuclear size [10,11], density distribution [12], fission barrier [13,14], deformation properties [15,16] etc. may change when a nucleon is replaced by a Λ hyperon. Studies show that inside a hypernucleus, the lambda–nucleus interaction is only slightly weaker than the nucleon–nucleus interaction. So it is expected that the Λ particle in the nucleus behaves very much like a nucleon. Thus, Λ particle can be considered as an impurity in the nucleus and one can employ it as a probe to the nuclear structure.

Various kinds of potentials [17–22] have been introduced to study the interaction of Λ particles within the nuclear medium. Traditionally Wood–Saxon [23] potential as well as Gaussian potential [10] are used to explain the Λ–nucleon interactions, which reproduce the measured Λ single-particle energies from medium to heavy hypernuclei quite well. In order to improve the overall fit to the single-particle energies, non-localities and density-dependent effects have been included in the non-relaivistic Hartree–Fock calculations with skyrme hyperon–nucleon (YN) interactions [24]. Also studies have been performed within the relativistic framework for calculating the microscopic hypernuclear structure properties [25–27].

A free Λ particle decays via strangeness-conserving weak interaction, $\Lambda \rightarrow N + \pi$. But within a nuclear environment this mesonic decay mode is suppressed due to the Pauli-blocking of the outgoing nucleon. So new non-mesonic decay modes, $\Lambda + N \rightarrow N + N$, will be dominant inside the hypernuclei. The exited Λ hypernucleus decays mainly by strong interaction through nucleon emission or cluster emission and the remaining strange nuclear system will come to its ground state by electromagnetic transition. Since the hypernuclear lifetimes are comparable to the nuclear reaction times, there is a possibility of detecting such decays from the hypernuclei. Dalitz *et al* [28] have observed the proton decay of the exited hypernuclei ${}^{12}_{\Lambda}$C, using the analysis of the emulsion data of (K^-, π^-) reaction on ^{12}C. They have identified three intermediate ${}^{12}_{\Lambda}$C* states, strongly excited, which decay through proton emission. The α emission from ${}^{10}_{\Lambda}$Be and ${}^{10}_{\Lambda}$B are studied by Majling *et al* [29–31] with the Nuclotron accelerator at JINR, Dubna. The authors proposed that such studies offer a unique possibility of determining the properties of weak interaction and will help to localise the difficulties of the hypernuclear non-mesonic decay puzzle. Theoretical studies on the emission of α and ^{14}C cluster from hyper Ac and Ra nuclei are studied by Santhosh and Nithya [32,33] and in their study they have compared them with the α and ^{14}C emission from normal Ac and Ra nuclei.

In the present work, we have studied the emission of α-particle from hyper Po, using the Coulomb and proximity potential model [34–36] with the inclusion of a Λ-nucleus potential. The half-lives of α emission from hyper Po nuclei are compared with the α half-lives of their corresponding nuclear core. The paper is organised as follows. A detailed description of the Coulomb and proximity model with the Λ-nucleus interaction is given in §2. The results and discussions are presented in §3 and §4 contains the summary of the entire work.

2. Theory

Studies on the properties of hypernuclei suggest that the hypernuclei can be viewed as a normal nuclear core plus a Λ hyperon. So, for calculating the α decay half-lives from hypernuclei, similar formalisms as the normal nuclei can be used. Here we have used the well-established Coulomb and proximity potential model (CPPM) with the inclusion of lambda-nucleus potential for calculating the α decay half-lives of hypernuclei.

In CPPM, the interacting potential between two nuclei is taken as the sum of Coulomb potential, proximity potential and centrifugal potential. It is given by

$$V = \frac{Z_1 Z_2 e^2}{r} + V_{\mathrm{p}}(z) + \frac{\hbar^2 \ell(\ell+1)}{2\mu r^2}, \quad \text{for } z > 0. \tag{1}$$

Here Z_1 and Z_2 are the atomic numbers of the daughter and the emitted cluster, r is the distance between fragment centres, z is the distance between the near surfaces of the fragments, ℓ represents the angular momentum and μ represents the reduced mass. V_{p} is the proximity potential given by Blocki *et al* [37,38] as

$$V_{\mathrm{p}}(z) = 4\pi\gamma b \left[\frac{C_1 C_2}{(C_1 + C_2)}\right] \Phi\left(\frac{z}{b}\right), \tag{2}$$

with the nuclear surface tension coefficient,

$$\gamma = 0.9517\left[1 - 1.7826(N-Z)^2/A^2\right]\ \mathrm{MeV/fm^2}. \tag{3}$$

Here N, Z and A represent the neutron, proton and mass number of the parent nuclei. Φ represents the universal proximity potential [38] given as

$$\Phi(\varepsilon) = -4.41 \mathrm{e}^{-\varepsilon/0.7176}, \quad \text{for } \varepsilon > 1.9475, \tag{4}$$

$$\Phi(\varepsilon) = -1.7817 + 0.9270\varepsilon + 0.0169\varepsilon^2 - 0.05148\varepsilon^3, \quad \text{for } 0 \le \varepsilon \le 1.9475, \tag{5}$$

with $\varepsilon = z/b$, where $b \approx 1$ fm is the width (diffuseness) of the nuclear surface. The Süsmann central radii C_i of the fragments are related to the sharp radii R_i as

$$C_i = R_i - \left(\frac{b^2}{R_i}\right)\ \mathrm{fm}. \tag{6}$$

For R_i, we use semi-empirical formula in terms of mass number A_i as [37]

$$R_i = 1.28 A_i^{1/3} - 0.76 + 0.8 A_i^{-1/3}\ \mathrm{fm}. \tag{7}$$

The potential for the internal part (overlap region) of the barrier is given as

$$V = a_0 (L - L_0)^n, \quad \text{for } z < 0, \tag{8}$$

where $L = z + 2C_1 + 2C_2$ fm and $L_0 = 2C$ fm, the diameter of the parent nuclei, which can be obtained using eq. (6). The constants a_0 and n are determined by the smooth matching of the two potentials at the touching point.

The barrier penetrability P using the one-dimensional Wentzel–Kramers–Brillouin approximation is given as

$$P = \exp\left\{-\frac{2}{\hbar}\int_a^b \sqrt{2\mu(V-Q)}\,\mathrm{d}z\right\}. \tag{9}$$

Here the mass parameter is replaced by $\mu = m A_1 A_2 / A$, where m is the nucleon mass and A_1, A_2 are the mass numbers of the daughter and the emitted cluster respectively. The turning points a and b are determined from the equation, $V(a) = V(b) = Q$, where Q is the energy released.

The half-life is given by

$$T_{1/2} = \left(\frac{\ln 2}{\lambda}\right) = \left(\frac{\ln 2}{\nu P}\right). \tag{10}$$

Here λ is the decay constant and assault frequency

$$\nu = \left(\frac{\omega}{2\pi}\right) = \left(\frac{2E_{\mathrm{v}}}{h}\right).$$

The empirical vibration energy E_v is given as [39]

$$E_v = Q\left\{0.056 + 0.039\exp\left[\frac{(4-A_2)}{2.5}\right]\right\}, \quad \text{for } A_2 \geq 4. \tag{11}$$

To incorporate the changes in potential due to Λ particle, we have included the potential, V_Λ, between the non-strange normal fragment and the fragment that contains lambda particle, in the expression for the interacting potential eq. (1). That is, as the α-particle penetrates the potential produced by the Coulomb force, nuclear force and centrifugal force, it also feels the potential generated by the Λ hyperon. The potential, V_Λ, between the non-strange and strange fragments is given by

$$V_\Lambda = \int \rho_\Lambda(r_1)V_{\Lambda N}(r_1 - r)\mathrm{d}^3r_1, \tag{12}$$

where $\rho_\Lambda(r_1)$ is the density distribution of Λ particle. The density distribution of Λ particle is taken from refs [10,11] and has the form

$$\rho_\Lambda(r) = \left(\pi b_\Lambda^2\right)^{-3/2}\mathrm{e}^{-r^2/b_\Lambda^2}. \tag{13}$$

Here $b_\Lambda = \sqrt{(4M_N + M_\Lambda)/4M_\Lambda b_\alpha}$, where M_N and M_Λ are the mass of the nucleon and Λ particle respectively and $b_\alpha = 1.358$ fm. The lambda–nucleon force is short range and the strength of lambda–nucleus potential $V_{\Lambda N}$ is smaller than the nucleon–nucleus potential. The lambda–nucleus potential, $V_{\Lambda N}$, is taken from ref. [22] and is given by

$$V_{\Lambda N} = \frac{-V_0}{1 + \exp[(r-c)/a]}. \tag{14}$$

Here the constants $V_0 = 27.4$ MeV, $a = 0.6$ fm and $c = 1.08A^{1/3}$.

By including the lambda–nucleus potential in eq. (1), the half-lives for the hypernuclei can also be determined using eq. (10).

The impurity effect of Λ hyperon on the radius of hypernuclei has also been analysed in various studies [16,18,40]. It is shown analytically that [40] for the higher mass hypernuclei, the ground-state r.m.s. radius varies linearly with $A_{\mathrm{core}}^{1/3}$, which is given by

$$\langle r^2\rangle = c_1 A_{\mathrm{core}}^{1/3} + b_1, \tag{15}$$

where c_1 and b_1 are energy-dependent quantities depending also on the potential parameters. The shrinkage of radius due to Λ hyperon is small for heavier nuclei. So the impurity effect of radius on the half-lives of hypernuclei is small for heavier ones. For example, in the case of ${}^{187}_{\Lambda}$Po the penetrability and half-life for α decay are 3.862×10^{-17} s^{-1} and 4.621×10^{-5} s. While giving a 1% shrinkage to the hypernuclear radius, the penetrability and half-life will change to 2.738×10^{-17} s^{-1} and 6.518×10^{-5} s.

3. Results and discussion

In the present paper we have examined how the half-lives of α emitting isotopes of Po will change in the presence of a Λ hyperon within the parent nuclei. The element Po is one of the members of the natural radioactive series with well-known decay properties [41]. A hyper Po nucleus can be formed when a neutron in the normal Po nucleus is replaced by a Λ hyperon. Such hypernuclei can be studied by considering the structure as a normal nuclear core plus a Λ hyperon. As many isotopes of Po are good α-emitters, hyper Po nuclei may also exhibit α decay. We have calculated the half-lives for the emission of α-particles from hyper ${}^{187-224}_{\Lambda}$Po and compared them with the α decay half-lives of the normal ${}^{186-223}$Po.

While calculating the α decay half-lives, the key quantity involved is the Q value for the decay. For normal nuclei, the Q value for α-emission can be calculated from the mass excess of the parent, α and daughter nuclei as

$$Q = \Delta M_\mathrm{p} - (\Delta M_\alpha + \Delta M_\mathrm{d}), \tag{16}$$

which is positive for a given decay. Here ΔM_p, ΔM_d and ΔM_α are the mass excess of the parent, daughter and the α-particle respectively. The mass excesses are taken from the recent mass excess table of Wang *et al* [42]. For computing the Q values for the emission of α-particles from the hyper Po nuclei, the binding energies of the parent, α and daughter nuclei are considered. As hypernuclei are considered as normal nuclear core plus Λ hyperon, the binding energies can be determined as

$$\mathrm{BE}(A, Z)_{\mathrm{hyper}} = \mathrm{BE}(A-1, Z)_{\mathrm{core}} + S_\Lambda, \tag{17}$$

where $\mathrm{BE}(A, Z)_{\mathrm{hyper}}$ is the binding energy of the hypernuclei, $\mathrm{BE}(A-1, Z)_{\mathrm{core}}$ is the binding energy of its non-strange core nucleus and S_Λ is the hyperon separation energy. The binding energies of the core nuclei are taken from the mass table of Wang *et al* [42]. For calculating the Λ hyperon separation energy, we have proposed a new formula

$$S_\Lambda = 28.31866\left[1 - \frac{4.17612}{A^{2/3}} + \frac{4.62356}{A^{4/3}}\right]. \tag{18}$$

The standard deviation of the formula is found to be 0.5533, which is minimum compared to other formulae [43–45] for finding the hyperon separation energy.

Tables 1 and 2 show the Q values and the logarithmic half-lives for the emission of α-particles from hyper ${}^{187-224}_{\Lambda}$Po and normal ${}^{186-223}$Po. The α decays of hyper

Table 1. Predictions for the α decay half-lives from hyper ${}^{187-205}_{\Lambda}\mathrm{Po}$ and non-strange ${}^{186-204}\mathrm{Po}$.

Decay	Q_α (MeV)	$\log T^{\alpha}_{1/2}$ (s)		Decay	Q_α (MeV)	$\log T^{\alpha}_{1/2}$ (s)	
		Without $V_{\Lambda N}$	With $V_{\Lambda N}$			Theor.	Exp.
${}^{187}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{183}_{\Lambda}\mathrm{Pb}$	8.452	−4.757	−5.214	${}^{186}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{182}\mathrm{Pb}$	8.537	−4.767	
${}^{188}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{184}_{\Lambda}\mathrm{Pb}$	7.930	−3.212	−3.668	${}^{187}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{183}\mathrm{Pb}$	8.016	−3.216	−2.854
${}^{189}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{185}_{\Lambda}\mathrm{Pb}$	8.036	−3.558	−3.994	${}^{188}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{184}\mathrm{Pb}$	8.119	−3.565	−3.561
${}^{190}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{186}_{\Lambda}\mathrm{Pb}$	7.646	−2.327	−2.761	${}^{189}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{185}\mathrm{Pb}$	7.730	−2.334	−2.456
${}^{191}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{187}_{\Lambda}\mathrm{Pb}$	7.646	−2.327	−2.761	${}^{190}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{186}\mathrm{Pb}$	7.729	−2.355	−2.609
${}^{192}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{188}_{\Lambda}\mathrm{Pb}$	7.446	−1.678	−2.091	${}^{191}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{187}\mathrm{Pb}$	7.529	−1.696	−1.658
${}^{193}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{189}_{\Lambda}\mathrm{Pb}$	7.272	−1.074	−1.487	${}^{192}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{188}\mathrm{Pb}$	7.355	−1.102	−1.492
${}^{194}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{190}_{\Lambda}\mathrm{Pb}$	7.048	−0.156	−0.571	${}^{193}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{189}\mathrm{Pb}$	7.130	−0.294	−0.611
${}^{195}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{191}_{\Lambda}\mathrm{Pb}$	6.942	0.230	−0.182	${}^{194}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{190}\mathrm{Pb}$	7.023	0.092	−0.407
${}^{196}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{192}_{\Lambda}\mathrm{Pb}$	6.703	1.165	0.753	${}^{195}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{191}\mathrm{Pb}$	6.781	1.030	0.667
${}^{197}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{193}_{\Lambda}\mathrm{Pb}$	6.612	1.521	1.110	${}^{196}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{192}\mathrm{Pb}$	6.694	1.366	0.763
${}^{198}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{194}_{\Lambda}\mathrm{Pb}$	6.368	2.552	2.139	${}^{197}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{193}\mathrm{Pb}$	6.441	2.426	
${}^{199}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{195}_{\Lambda}\mathrm{Pb}$	6.266	2.989	2.576	${}^{198}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{194}\mathrm{Pb}$	6.346	2.827	
${}^{200}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{196}_{\Lambda}\mathrm{Pb}$	6.032	4.062	3.649	${}^{199}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{195}\mathrm{Pb}$	6.111	3.893	
${}^{201}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{197}_{\Lambda}\mathrm{Pb}$	5.939	4.494	4.081	${}^{200}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{196}\mathrm{Pb}$	6.017	4.325	
${}^{202}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{198}_{\Lambda}\mathrm{Pb}$	5.756	5.395	4.983	${}^{201}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{197}\mathrm{Pb}$	5.835	5.212	
${}^{203}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{199}_{\Lambda}\mathrm{Pb}$	5.659	5.882	5.471	${}^{202}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{198}\mathrm{Pb}$	5.736	5.703	
${}^{204}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{200}_{\Lambda}\mathrm{Pb}$	5.455	6.970	6.560	${}^{203}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{199}\mathrm{Pb}$	5.532	6.780	
${}^{205}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{201}_{\Lambda}\mathrm{Pb}$	5.443	7.018	6.609	${}^{204}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{200}\mathrm{Pb}$	5.521	6.822	

Table 2. Predictions for the α decay half-lives from hyper ${}^{206-224}_{\Lambda}\mathrm{Po}$ and non-strange ${}^{205-223}\mathrm{Po}$.

Decay	Q_α (MeV)	$\log T^{\alpha}_{1/2}$ (s)		Decay	Q_α (MeV)	$\log T^{\alpha}_{1/2}$ (s)	
		Without $V_{\Lambda N}$	With $V_{\Lambda N}$			Theor.	Exp.
${}^{206}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{202}_{\Lambda}\mathrm{Pb}$	5.283	7.916	7.508	${}^{205}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{201}\mathrm{Pb}$	5.361	7.708	
${}^{207}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{203}_{\Lambda}\mathrm{Pb}$	5.286	7.880	7.473	${}^{206}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{202}\mathrm{Pb}$	5.363	7.679	
${}^{208}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{204}_{\Lambda}\mathrm{Pb}$	5.176	8.515	8.110	${}^{207}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{203}\mathrm{Pb}$	5.252	8.312	
${}^{209}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{205}_{\Lambda}\mathrm{Pb}$	5.175	8.504	8.100	${}^{208}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{204}\mathrm{Pb}$	5.251	8.301	7.961
${}^{210}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{206}_{\Lambda}\mathrm{Pb}$	4.939	9.961	9.559	${}^{209}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{205}\mathrm{Pb}$	5.015	9.741	9.592
${}^{211}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{207}_{\Lambda}\mathrm{Pb}$	5.367	7.343	6.939	${}^{210}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{206}\mathrm{Pb}$	5.443	7.147	7.078
${}^{212}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{208}_{\Lambda}\mathrm{Pb}$	7.555	−2.046	−2.459	${}^{211}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{207}\mathrm{Pb}$	7.630	−2.440	−0.287
${}^{213}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{209}_{\Lambda}\mathrm{Pb}$	8.915	−6.051	−6.470	${}^{212}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{208}\mathrm{Pb}$	8.990	−6.557	−6.524
${}^{214}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{210}_{\Lambda}\mathrm{Pb}$	8.497	−4.923	−5.340	${}^{213}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{209}\mathrm{Pb}$	8.571	−5.416	−5.429
${}^{215}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{211}_{\Lambda}\mathrm{Pb}$	7.795	−2.828	−3.243	${}^{214}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{210}\mathrm{Pb}$	7.869	−3.287	−3.786
${}^{216}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{212}_{\Lambda}\mathrm{Pb}$	7.488	−1.820	−2.234	${}^{215}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{211}\mathrm{Pb}$	7.562	−2.268	−2.749
${}^{217}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{213}_{\Lambda}\mathrm{Pb}$	6.868	0.118	−0.275	${}^{216}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{212}\mathrm{Pb}$	6.942	0.005	−0.839
${}^{218}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{214}_{\Lambda}\mathrm{Pb}$	6.624	1.098	0.702	${}^{217}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{213}\mathrm{Pb}$	6.699	0.972	0.185
${}^{219}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{215}_{\Lambda}\mathrm{Pb}$	6.077	3.522	3.124	${}^{218}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{214}\mathrm{Pb}$	6.150	3.379	2.269
${}^{220}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{216}_{\Lambda}\mathrm{Pb}$	5.878	4.478	4.080	${}^{219}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{215}\mathrm{Pb}$	5.952	4.326	
${}^{221}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{217}_{\Lambda}\mathrm{Pb}$	5.390	7.062	6.666	${}^{220}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{216}\mathrm{Pb}$	5.394	7.281	
${}^{222}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{218}_{\Lambda}\mathrm{Pb}$	5.012	9.313	8.921	${}^{221}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{217}\mathrm{Pb}$	5.145	8.746	
${}^{223}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{219}_{\Lambda}\mathrm{Pb}$	4.539	12.520	12.132	${}^{222}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{218}\mathrm{Pb}$	4.651	12.007	
${}^{224}_{\Lambda}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{220}_{\Lambda}\mathrm{Pb}$	4.428	13.336	12.950	${}^{223}\mathrm{Po} \to {}^{4}\mathrm{He} + {}^{219}\mathrm{Pb}$	4.411	13.779	

Po nuclei are compared with the α decays of their corresponding normal core nuclei. A small difference can be seen while comparing the Q values of hyper Po nuclei and their corresponding nuclear core. The third column in the tables indicates the half-life values for α emission from hyper Po nuclei without considering the lambda–nucleon (Λ–N) interaction. That is, the half-lives are computed only by taking into account the changes in Q value. By comparing these half-lives with the half-lives of normal Po nuclei, it is evident that, generally the half-lives of hyper Po nuclei are greater than the half-lives of normal Po nuclei. But it is well known that apart from the nucleon–nucleon (N–N) interaction, the Λ–Ninteraction also plays an important role in hypernuclei. So, by considering the Λ–N interaction, the half-lives are recalculated and included in column 4. It can be understood that the inclusion of Λ–N interaction changes the half-lives of the decay. From tables 1 and 2, it is clear that the half-lives of hyper ${}^{A+1}_{\Lambda}$Po isotopes without $V_{\Lambda N}$ is longer than ^{A}Po. But if we consider $V_{\Lambda N}$, the half-lives become shorter than those without $V_{\Lambda N}$. While calculating the half-lives without $V_{\Lambda N,}$ we are only considering the changes in Q value due to the presence of the Λ particle. But while calculating the half-lives with $V_{\Lambda N}$, we are considering both the changes in Q value and potential due to the presence of Λ particle. Because $V_{\Lambda N}$ is always attractive, the total potential V will decrease (because of the negative sign in $V_{\Lambda N}$). Then the driving potential (V–Q) will decrease. Note that Q value used is the same in both cases. As a result, penetrability increases which will cause a decrease in half-life. So by including $V_{\Lambda N}$ potential, the half-life decreases compared to the half-lives without $V_{\Lambda N}$.

From the tables it is found that the isotopes ${}^{187-224}_{\Lambda}$Po and the isotopes ${}^{186-223}$Po may exhibit α decay. Even though the theoretical results suggest α decay from the hypernuclei, the hypernuclei will convert into normal nuclei by mesonic or non-mesonic decay modes within picoseconds. Since the α half-lives of normal Po nuclei are within the experimental limits, the α emission from hyper Po nuclei can be detected in laboratory in a cascade process. That is, it may be possible to construct experiments in which α decay of normal Po nuclei can be used as a tool for identifying hyper Po nuclei, because the hypernuclei will decay into normal nuclei through non-mesonic decay modes. So, such two-step processes can be useful for identifying hypernuclei. A detailed investigation of α-particles accompanying the weak decay of ${}^{10}_{\Lambda}$Be and ${}^{10}_{\Lambda}$B hypernuclei were performed in the experiments at the Nuclotron of the Joint Institute for Nuclear Research (JINR, Dubna) [29–31]. The detection of a few groups of correlated α pairs from ${}^{10}_{\Lambda}$Be and ${}^{10}_{\Lambda}$B will furnish information about decays to specific states of the product nuclei (^{8}Be*, ^{8}Li, ^{8}B). Through this analysis, it is possible to get information about the weak decays of hypernuclei.

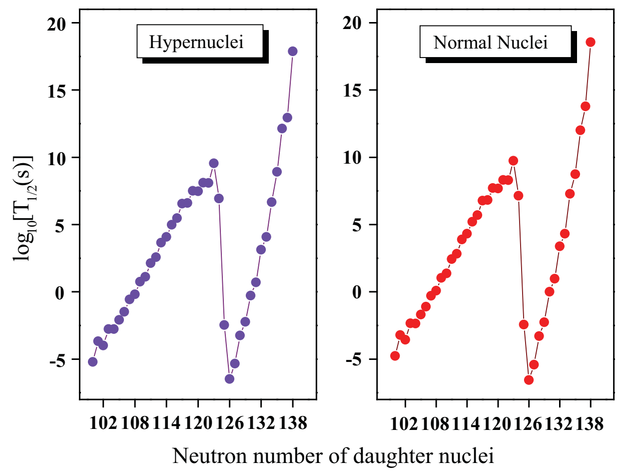

Figure 1. Plot for neutron number of the daughter nuclei vs. $\log_{10}T_{1/2}$ for hyper and normal isotopes of Po.

A comparison of the predicted half-lives of 21 isotopes of normal Po with their corresponding experimental values [46] is also performed. It is seen that the predicted half-lives match very well with the experimental results [46]. We have calculated the standard deviation using,

$$\sigma = \left\{ \frac{1}{(n-1)} \sum_{i=1}^{n} \left(\log_{10} T_i^{\text{cal.}} - \log_{10} T_i^{\text{exp.}} \right)^2 \right\}^{1/2}. \tag{19}$$

The estimated standard deviation is found to be 0.6720.

In the present work, the α decay half-lives are calculated by assuming non-zero angular momentum transfer. This is because the angular momentum ℓ carried away in the α decay process is found to be very small ($\approx 5\hbar$) and its contribution to the half-life is also shown to be small [39].

Figure 1 shows the plot of neutron number of the daughter nuclei vs. $\log_{10}T_{1/2}$ for both hyper and normal isotopes of Po. From the figure it is noted that the variation is the same in the two cases. A dominant dip in the logarithmic half-lives can be seen at $N = 126$, that is, the logarithmic half-life is found to be minimum for the decay leading to the daughter nuclei with $N = 126$. This indicates the neutron shell closure of the hyper and normal nuclei at $N = 126$. Figure 2 represents the Geiger–Nuttal (G–N) plot for hyper and normal nuclei. The figure shows that the linearity of G–N law is exhibited in the case of hypernuclei also. The inclusion of Λ–N potential does not change the straight line behaviour of the G–N law.

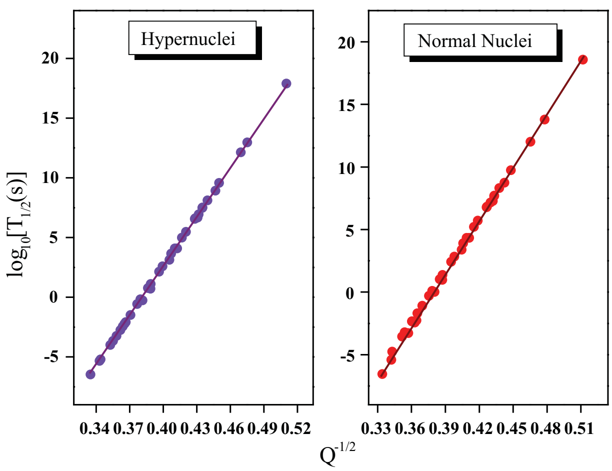

Figure 2. Plot for G–N law for hyper and normal isotopes of Po.

4. Summary

Alpha decay half-lives of hyper and normal isotopes of Po are estimated and compared in the present study. It is seen that the inclusion of Λ–N interaction will change the α half-lives of the isotopes. It is also found that the neutron shell closure at $N = 126$ is the same for both normal and hypernuclei. The G–N law for α decay is seen to be unaltered in the case of hypernuclei. The hypernuclei will decay into normal nuclei by mesonic or non-mesonic decay modes. As the half-lives of normal Po nuclei are well within the experimental limits, our theoretical results suggest experimental verification of the α emission from hyper Po nuclei in a cascade process.

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