Preformation of α-particle for favoured transitions using proximity potential

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Introduction

α decay studies are an important tool for obtaining information about a number of nuclear properties like ground state half life, ground state energy, nuclear spin, parity, shell effects and also the nuclear interaction. In 1928, α decay was independently explained by Gamow, and by Condon and Gurney as a quantum tunnelling process. The α decay constant (λ) is expressed as the product of three terms [1],

$$\lambda = P_0 \nu_0 P \quad (1)$$

Here, P_0 is the preformation probability of the α-particle inside the nucleus, ν_0 is the assault frequency of the α-particle at the barrier, and P is the probability of penetration of the α particle through the potential barrier.

In this work we would present calculations of preformation probability, P_0, for favoured transitions of α-decay of all nuclides apart from even-even nuclides. Results for even-even nuclides were presented in [1].

Formalism

The α preformation probability (P_0) is given by[1],

$$P_0 = \frac{ln(2)}{T_\alpha^{expt} \nu_0 P} \quad (2)$$

where, T_α^{expt} is the experimental α-decay half-life. For calculating the barrier penetrability (P) the WKB approximation is used and is given by,

$$P = exp\Big(-\frac{2}{\hbar}\int_a^b \sqrt{2\mu(V-Q)}dr \Big) \quad (3)$$

Here, μ and V are the reduced mass and the interacting potential between the α-particle and the residual nucleus, respectively, and Q is the Q value of the disintegration process. The turning points a and b are determined from the equation, $V(a) = V(b) = Q$. The interaction potential is given by,

$$V = V_C(r) + V_N(r) + \frac{\hbar^2 l(l+1)}{2\mu r^2} \quad (4)$$

Assuming spherical distribution of charge between the two nuclei, the Coulomb potential (V_C) is given by,

$$V_C = \frac{Z_1 Z_2 e^2}{r} \quad (5)$$

For the nuclear potential (V_N), the proximity potential (Prox 76) is chosen [1]. The assault frequency, ν_0, is given by the quantum mechanical formula [1],

$$\nu_0 = \frac{1}{h}\Big\{ \frac{Q}{\big(1+\frac{4}{A}\big)} + \frac{h^2}{4\mu R^2} \Big\} \quad (6)$$

where, h is Plank's constant, A is the mass number of the daughter nucleus, Q is the Q-value of the α disintegration, and R is the radius of the parent nucleus and is given by,

$$R = 1.28A^{1/3} + 0.8A^{-1/3} - 0.76 \quad fm \quad (7)$$

Results

Emission of α particle from the nucleus follows the selection rule,

$$|I_j - I_i| \le \ell \le I_j + I_i \quad \text{and} \quad \frac{\pi_i}{\pi_j} = (-1)^\ell \quad (8)$$

where, ℓ is the angular momentum carried by the α particle, and I_j, π_j, and I_i, π_i are the

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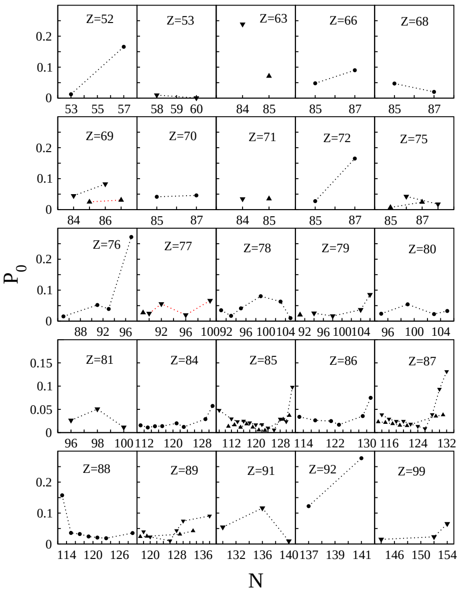

FIG. 1: Preformation probability (P_0) versus neutron number (N) for different isotopes of g.s. $\rightarrow$ g.s. favoured α-transitions. Circle ($\bullet$) is used for even Z and odd N, uptriangle ($\blacktriangle$) is used for odd Z and odd N, and downtriangle ($\blacktriangledown$) is used for odd Z and even N of parent nuclei.

spin and parity of the parent and daughter nuclei, respectively. In this work only favoured transitions are considered for which, $I_j = I_i$, and $\pi_j = \pi_i$, and hence, ℓ=0. The experimental half lives (T_α^{expt}) and the Q-values used in the calculation for P_0 are taken from the

TABLE I: Mean ($\bar{x}$) of preformation probability (P_0) values for the four different transition types, and the four different parent nuclei. n denotes the number of transitions. The data for even-even parent nuclei is taken from [1].

transition	Z N	n	$\bar{x}$
all	even-even	179	0.097592
all	even-odd	80	0.053705
all	odd-even	98	0.050297
all	odd-odd	55	0.027198
g.s. $\rightarrow$ g.s.	all	324	0.074519
g.s. $\rightarrow$ i.s.	all	19	0.065726
i.s. $\rightarrow$ g.s.	all	20	0.045198
i.s. $\rightarrow$ i.s.	all	49	0.038644

latest data of Brookhaven National Laboratory, New York, USA [2] and NUBASE2016 [3]. The mean ($\bar{x}$) values of the preformation probability (P_0) grouped according to transition type and nucleon number are shown in Table 1 [4]. As expected, average values of P_0 are highest for even-even nuclei because all the nucleons are paired and therefore clustering of a pair of protons and neutrons to form an α-particle would be relatively easier. Likewise, average values of P_0 are minimum for odd-odd nuclei. Average P_0 value is the highest for ground state to ground state (g.s. $\rightarrow$ g.s.) transition, and is the minimum for isomeric state to isomeric state (i.s. $\rightarrow$ i.s.) transition. The above result indicates that the probability of preformation (P_0) of the α-particle is greater in the ground state than in the isomeric state. In Fig. 1, P_0 versus neutron number (N) is shown for various isotopes [4]. The minimum value of P_0 at the neutron magic number, N=126 is to be noted for Z=85, 87 and 89. This is expected because nuclei are stable at magic numbers, and would resist the formation of an α-particle as it would reduce the neutron number to 124.

Conclusion

Further studies on P_0 can also be carried out with other potentials, like, the relativistic mean field theory, DDM3Y interaction, Skyrme-Hartree-Fock mean field potential, etc. P_0 values can also be calculated for unfavoured transitions for which the angular momentum (ℓ) of the α-particle (Eq. 4) takes the minimum value allowed by Eq. (8).

References

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