Log $f_{1u}t$ values for forbidden unique β^- transitions in ^{74,76,78}As isotopes

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Introduction

The nuclear β-decay plays an important role to study the structure and properties of atomic nuclei and requires a theoretical model to study β-decay properties. The β-decay transitions are divided into allowed and forbidden types based on the angular momentum of the leptons. For the Kth forbidden unique (FU) transition, $\Delta J = K + 1$, here, the angular momentum change between the initial and final nuclear states is maximal and parity changes according to $\Delta\pi = (-1)^K$. So, the decay rate and the shape factor in the case of FU transitions are simplified as they depend on only one nuclear matrix element. A recent systematics of log ft values for β^- , β^+ and EC decay is presented with the updated Q-values from AME 2020 [1]. Recently, the partial half-lives are calculated using the nuclear shell model (SM) for the higher forbidden unique β^- transitions [2].

In the present work, the log $f_{1u}t$ values are calculated in the cases of the 1st FU transitions ^{74}As$(2^-) \rightarrow {}^{74}$Se (0^+), ^{76}As$(2^-) \rightarrow {}^{76}$Se (0^+) and ^{78}As$(2^-) \rightarrow {}^{78}$Se (0^+). These transitions are from the 2^- g.s. of the odd-odd nuclei to the 0^+ g.s. of even-even nuclei. We have employed SM to calculate the nuclear matrix elements.

Formalism

For allowed and forbidden types of β-decay, the detailed formalism is given in the book by Behrens and Bühring [3].

The partial half-life is given as

$$t_{1/2} = \frac{\kappa}{\tilde{C}}, \tag{1}$$

where $\kappa = 6289$ s. The integrated shape function $\tilde{C}$ is given as

$$\tilde{C} = \int_1^{w_0} C(w_e) p w_e (w_0 - w_e)^2 F_0(Z, w_e) dw_e, \tag{2}$$

where p and w_e are the electron momentum and energy, respectively. The w_0 is the end-point energy which is the highest amount of energy acquired by the emitting electron. The quantity $C(w_e)$ is the shape factor and $F_0(Z, w_e)$ is the Fermi function for the daughter nucleus with proton number Z. The shape factor $C(w_e)$ can be expressed as

$$C(w_e) = \sum_{k_e, k_\nu, K} \lambda_{k_e} \Big[M_K(k_e, k_\nu)^2 + m_K(k_e, k_\nu)^2 - \frac{2\gamma_{k_e}}{k_e w_e} M_K(k_e, k_\nu) m_K(k_e, k_\nu) \Big]. \tag{3}$$

Where, k_e and k_ν are positive integers. The quantities $M_K(k_e, k_\nu)$ and $m_K(k_e, k_\nu)$ contain all the nuclear structure information in the form of nuclear matrix elements (NMEs) and other kinematic factors.

For the 1st FU transitions we calculated the log $f_{1u}t$ values as below

$$\log f_{1u}t \equiv \log(f_{1u}t_{1/2}). \tag{4}$$

For FU transitions, the phase space factor is given by f_{Ku} which is expressed as

$$f_{Ku} = \Big(\frac{3}{4}\Big)^K \frac{(2K)!!}{(2K+1)!!} \times \int_1^{w_0} C_{Ku}(w_e) p w_e (w_0 - w_e)^2 F_0(Z_f, w_e) dw_e, \tag{5}$$

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TABLE I: Comparison of $\log f_{1u}t$ values between experimental, SM and pnQRPA for 1st FU β^- transitions in the cases of ^{74,76,78}As.

		Energy		$\log f_{1u}t$			
Transition	Decay Mode	Q(keV)	Iβ^-	Expt. [4]	pnQRPA [5]	SM	Interaction
^{74}As(2^-) $\rightarrow$ ^{74}Se (0^+)	1st FU	1353.1(17)	18.6	9.37(6)	9.01	9.37	gwbxg
^{76}As(2^-) $\rightarrow$ ^{76}Se (0^+)	1st FU	2960.6(9)	55.8	9.7003(33)	9.31	9.19	gwbxg
^{78}As(2^-) $\rightarrow$ ^{78}Se (0^+)	1st FU	4209(10)	32	9.64(11)	9.73	9.07	gwbxg

where $C_{Ku}(w_e)$ is the shape function for Kth FU transition and expressed as

$$C_{Ku}(w_e) = \sum_{k_e+k_\nu=K+2} \frac{\lambda_{k_e} p^{2(k_e-1)} (w_0 - w_e)^{2(k_\nu-1)}}{(2k_e-1)!(2k_\nu-1)!}. \quad (6)$$

For 1st FU transitions $f_{1u} = 12 f_{K=1,u}$.

Results

In the present work, we have calculated the $\log f_{1u}t$ for ^{74,76,78}As isotopes using nuclear SM. We have used the gwbxg effective interaction to calculate the one body transition densities (OBTDs) and no truncation is employed. The model space of gwbxg effective interaction consists of $1f_{5/2}$, $2p_{3/2}$, $2p_{1/2}$, $1g_{9/2}$ proton orbitals and $2p_{1/2}$, $1g_{9/2}$, $1g_{7/2}$, $2d_{5/2}$, $2d_{3/2}$, and $3s_{1/2}$ neutron orbitals and single particle energies (SPEs) (in MeV) used in this interaction are $-5.322, -6.144, -3.941, -1.250$, for the proton orbitals, and $-0.696, -2.597, +5.159, +1.830, +4.261, +1.741$ for the neutron orbitals, respectively using ^{66}Ni as a core. For the $\log f_{1u}t$ values, we have used the axial-vector coupling constant g_A=1.00. The g.s. to g.s. Q-values are taken from recent data sheet AME 2020 [6]. The comparison of $\log f_{1u}t$ values between experimental, proton-neutron quasiparticle random-phase approximation (pnQRPA) and SM results are shown for 1st FU β^- transitions of ^{74,76,78}As isotopes along with their branching ratios (Iβ^-) in Table I. Our SM results for $\log f_{1u}t$ are in reasonable agreement with the experimental results as well as with the pnQRPA results except in the case of ^{78}As(2^-) $\rightarrow$ ^{78}Se (0^+).

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References

[1] S. Turkat *et. al.*, "Systematics of log ft values for β^-, and EC/β^+transitions", At. Data Nucl. Data Tables **152**, 101584 (2023).

[2] A. Saxena and P.C. Srivastava,"Higher forbidden unique β^- decay transition and shell model interpretation", Nucl. Phys. A **1051**, 122939 (2024).

[3] H. Behrens and W. Bühring, *Electron Radial Wave Functions and Nuclear Beta-Decay* (Clarendon Press, 1982).

[4] National Nuclear Data Center(NNDC), ENSDF database, https://www.nndc.bnl.gov/ensdf/.

[5] J. Suhonen, *From Nucleons to Nucleus: Concept of Microscopic Nuclear Theory*, (Springer, Berlin 2007).

[6] M. Wang *et. al.*, "The AME 2020 atomic mass evaluation (II). Tables, graphs and references", Chin. Phys. C **45**(3), 030003(2021).