First forbidden beta-decay properties of ^{137}Te using shell-model

Shweta Sharma,* Praveen C. Srivastava,† and Anil Kumar
Department of Physics, Indian Institute of Technology Roorkee, Roorkee 247667, India

Introduction

Understanding the abundance pattern of r-process nuclei is one of the important tasks in nuclear physics. These r-process nuclei are neutron-rich nuclei, and it is highly desirable to evaluate the nuclear structure properties of these neutron-rich nuclei both experimentally and theoretically. The nuclear shell model has been proven to be one of the best models to predict the nuclear structure properties of nuclei with neutron or proton numbers near magic numbers. ^{137}Te is near to the doubly magic nuclei ^{132}Sn. Thus, it is interesting to study the decay properties of this nucleus. This nucleus shows forbidden beta decay transitions. Beta decay can be characterized as allowed and forbidden beta decay. When we move towards the higher mass region, the first forbidden beta decay transitions compete with the allowed beta decay. Also, the transition probabilities get overestimated or underestimated during nuclear shell-model calculations. Therefore, the quenching factor is used to evaluate beta-decay properties properly. This quenching factor is being included in the expression of weak coupling constants g_V and g_A such that g_V is the vector coupling constant and g_A is the axial vector coupling constant. Further, in $\Delta J = 0^-$ transitions, the matrix element gets enhanced with the help of mesonic enhancement factor ϵ_{MEC}. Thus, we have to consider all these factors in shell-model calculations.

Recently, the beta decay spectroscopy of ^{137}Te was done at LOHENGRIN, and the beta decay properties such as $\log ft$ values from the ground state of ^{137}Te to ground and several excited states of ^{137}I were reported as given in Ref. [1]. In the present work, the $\log ft$ values and average shape factors corresponding to few transitions are calculated and compared with the available experimental data.

Formalism

The beta-decay formalism using impulse approximation is briefed here. One can find detailed formalism in Ref. [2]. In beta-decay, the half-life is given by

$$t_{1/2} = \frac{\ln(2)}{\int_{m_e c^2}^{W_0} P(W_e) dW_e}, \tag{1}$$

where W_0 is the end-point energy and m_e is the electron mass. The integrand in the denominator is the transition probability which is given as,

$$P(W_e)dW_e = \frac{G_{\rm F}^2}{(\hbar c)^6}\frac{1}{2\pi^3\hbar}C(W_e)p_e c W_e \times (W_0 - W_e)^2 F_0(Z, W_e)dW_e, \tag{2}$$

where G_F is the Fermi coupling constant and W_e and p_e are the electron energy and momentum, respectively. $C(W_e)$ is the shape factor, and $F_0(Z, W_e)$ is the Fermi function included to account for the Coulomb force between electron and nucleus.

Also, the average shape factor is given by,

$$\overline{C(w_e)} = f/f_0 \,. \tag{3}$$

where f is the phase space factor and f_0 is the phase space factor for the allowed transition. The average shape factor in the case of the first forbidden transition is given by,

$$\overline{C(w_e)}(fm^2) = \frac{6289\lambda_{\rm Ce}^2}{ft} = \frac{9378\times 10^5}{ft}, \tag{4}$$

*Electronic address: `s_sharma@ph.iitr.ac.in`
†Electronic address: `praveen.srivastava@ph.iitr.ac.in`

TABLE I: Comparison between experimental and shell-model $\log ft$ values and average shape factors for transitions from ^{137}Te((7/2$^-$)) to ground and excited states of ^{137}I. Here, FNU and FU denote forbidden nonunique and forbidden unique transition, respectively. The double bracket corresponds to the unconfirmed states.

J_f^π		Decay mode	Energy	Iβ^-	$\log ft$		$[\overline{C(w_e)}]^{1/2}$	
Expt.	SM		(keV)		Expt.	SM	Expt.	SM
$7/2^+$	$7/2_1^+$	1st FNU	0.0	42(9)	5.8(1)	5.712	38.553	42.640
$5/2^+$	$5/2_1^+$	1st FNU	243.6(8)	13.0(29)	6.2(1)	6.037	24.325	29.334
$((3/2^+, 5/2^+))$	$3/2_1^+$	1st FU	373.1(7)	4.6(10)	6.6(2)	11.357	15.348	0.064
$((3/2^+, 5/2^+))$	$5/2_2^+$	1st FNU	373.1(7)	4.6(10)	6.6(2)	6.433	15.348	18.611
$9/2^+$	$9/2_1^+$	1st FNU	554.2(10)	7.1(16)	6.4(1)	6.964	19.322	10.096

where λ_{Ce} is the reduced Compton wavelength of the electron.

Results

In the present work, we have calculated the $\log ft$ and average shape factors from the ground state of ^{137}Te to ground and several excited states of ^{137}I. The jj56pnb interaction is used with ^{132}Sn as a core. The model space chosen is $1f_{7/2}, 0h_{9/2}, 1f_{5/2}, 2p_{3/2}, 2p_{1/2}, 0i_{13/2}$ for neutrons and $0g_{7/2}, 1d_{5/2}, 1d_{3/2}, 2s_{1/2}, 0h_{11/2}$ for protons. The values of the quenching factor and mesonic enhancement factor are taken from Ref. [3] where ϵ_{MEC}=2.0 and g_A=0.64 for A=137. Our shell-model results for beta decay properties agree pretty well with the experimental results. For instance, in Table I, the shell-model $\log ft$ value for ^{137}I($7/2_1^+$) is 5.712 which is very close to the experimental value i.e., 5.8(1). Also, for transition ^{137}I($5/2_1^+$) at energy 243.6(8) keV, the shell-model $\log ft$ value is 6.037 whereas the experimental value is 6.2(1). This shows the credibility of the shell model in the evaluation of beta-decay properties. Further, with the help of shell-model calculations, we can also predict a particular spin parity state where the experiment is unable to predict. For instance, in case of transition ^{137}I(($3/2_1^+, 5/2_2^+$)), the $\log ft$ value in case of $5/2_2^+$ is 6.433 which is near to the experimental value i.e. 6.6(2). Whereas the $\log ft$ value in the case of $3/2_1^+$ is 11.357, which is very far from the experimental $\log ft$ value. Thus, we can infer from this discussion that $5/2_2^+$ can be the assigned spin parity state at energy 373.1(7) keV. Further, in case of ^{137}I($9/2_1^+$) transition the shell-model $\log ft$ value i.e. 6.964 also matches very well with the experimental value i.e. 6.4(1). Comprehensive details will be reported in our forthcoming publication [4].

S. S. would like to acknowledge CSIR-HRDG (India) for the financial support for her Ph.D. thesis work. We acknowledge a research grant from SERB (India), No. CRG/2019/000556.

References

[1] M. Si *et al.*, "new β-decay spectroscopy of the ^{137}Te nucleus", Phys. Rev. C **106**, 014302 (2022).

[2] S. Sharma, P.C. Srivastava, A. Kumar, T. Suzuki, "Shell-model description for the properties of the forbidden β^- decay in the region 'northeast' of ^{208}Pb", Phys. Rev. C **106**, 024333 (2022).

[3] J. Kostensalo, J. Suhonen, "Mesonic enhancement of the weak axial charge and its effect on the half-lives and spectral shapes of first- forbidden J$^+ \leftrightarrow$ J$^-$ decays", Phys. Lett. B **781**, 480 (2018).

[4] S. Sharma, P.C. Srivastava, A. Kumar (under preparation).