The first forbidden unique beta transitions in the beta decays of ^{177}Lu and ^{177}Yb

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Introduction

There are many instances of first forbidden unique (1u) beta transitions ($\Delta J=\pm 2$, $\Delta\pi= -$) in the 160<A< 180 region [1]. The beta unstable Lutetium (Z =71) isotopes and some Ta isotopes that have odd A values between 167 and 183 have the same ground state spin parity of $J^{\pi}=7/2^{+}$ (band assignment of $7/2^{+}[404]$) [2] and are thus good candidates to study beta transitions systematically. These undergo $\beta^{-}/\beta^{+}/\varepsilon$ decay to their odd N neighbors. It is known that rotational bands based on the $f_{7/2}$ orbital are seen at not very high excitation energies in this region. Thus beta transitions from the ground state of the Lu isotopes ($J^{\pi}=7/2^{+}$) to the low spin members of the $7/2^{-}[514]$ rotational band of the daughter nucleus are expected to be observed, if the said band is identified and is energetically accessible, given that these transitions are not K-forbidden. Likewise, beta transitions from the $7/2^{-}[514]$ ground state to the rotational levels of $7/2^{+}[404]$ band are also to be expected. In particular, the beta transition to the 11/2 level of either rotational band would be of the first forbidden unique type with expected *log ft* value of 8.5 or higher. This 1u beta branching has indeed been noted in some of the odd A isotopes (^{177}Lu, ^{177}Ta, ^{175}Yb, etc.). In many Lu isotopes, it is seen that there is no beta branching to this particular level, although there may be transitions to other 11/2- states. It is further observed in literature that there is some ambiguity regarding the beta feeding to the $J^{\pi}=11/2$ level even in those nuclei, where such transitions were considered to be established. For example, earlier studies [3,4] had reported a low intensity beta feeding to the $11/2^{-}$ level at 249.67 keV in ^{177}Hf, but in the more recent measurement of Schotzig et al [5] there is no report of a direct feeding. The same is found in the case of the 11/2+ level in ^{175}Lu populated by the β^{-} decay of ^{175}Yb and others. Weak beta branches are usually determined from the intensity balance of the final level. In such cases, errors in gamma or conversion electron intensities or the existence of unobserved transitions contribute to errors in beta feeding intensities. The present work is aimed at resolving these ambiguities by precision measurements of gamma and conversion electron intensities of transitions in ^{177}Hf and in ^{175}Lu, and thus calculating the beta branching intensities to the said levels accurately.

Experiment

The samples of the radioisotope ^{177}Lu and ^{175}Yb dissolved in HCl solution (produced by the neutron irradiation of enriched ^{176}Lu and Yb_2O_3) were obtained from the Board of Radiation and Isotope Technology, BARC, Mumbai. The source activity was about 10 mCi. In order to minimize back scattering and self absorption effects, very thin sources with count rates < 1000 counts were prepared for the electron spectroscopy, by drying the source solution on aluminized Mylar foils, supported on 1.0 cm diameter aluminum rings. The beta and conversion electron spectra were acquired with a Mini-Orange Spectrometer [6].

The gamma spectra were acquired with a 60 cc co-axial HPGe detector (EG&G ORTEC, FWHM = 1.8 keV (1.33 MeV) & 665 eV (5.9 keV)). The unshielded detector's energy and efficiency calibration were performed with IAEA standard sources. The gamma singles spectrum was acquired at a source to detector distance of 25 cm. Gamma Vision-32 and FIT were used for spectral acquisition and analysis. The internal conversion coefficients (α) of the transitions in either nucleus were determined by the Normalized Peak to Gamma (NPG) method.

Results and Discussion

The energies and intensities of the 6 well known gammas in ^{177}Hf and in ^{175}Lu are shown in Table 1 along with their relative intensities. The uncertainties in the present relative intensities resulted predominantly from errors in the peak area determination and the interpolation of efficiency that were determined with about 1% error on the average. The (α) values are reported elsewhere [7, 8].

The beta decay branching ratios from the ground state of the parent nucleus were calculated from the total transition intensity balance at each level of the daughter using the computer code GTOL. The program uses the total gamma and conversion electron intensities feeding and depopulating each level in the decay scheme. The total theoretical conversion coefficients were taken from the Nuclear Data Sheets with a 3% relative uncertainty assigned to those values that were given without uncertainty. A second independent calculation was also carried out with the measured gamma intensities and the presently determined total conversion coefficient values $(\alpha_T = \alpha_K + \alpha_L + \alpha_M)$ with their respective uncertainties. The resulting beta branching percentages are summarized in the Table 2. The present intensities I_β of either decay are in good agreement with earlier studies.

Table 1: Gamma energies and relative intensities in the decay of ^{177}Lu and ^{175}Yb

^{177}Lu → ^{177}Hf		^{175}Yb → ^{175}Lu	
E_γ (keV)	I_γ	E_γ (keV)	I_γ
71.644^{1}	1.780 7	113.807 2	30.53 21
112.947^{1}	62.15 5	137.671 6	1.73 4
136.724^{4}	0.543 6	144.876 1	5.12 4
208.366 1	**100.0 8**	251.510 4	1.31 2
249.673 8	1.982 4	282.525 1	46.6 4
321.327 1	2.470 7	**396.329 1**	**100.0 7**

Table 2: Beta intensities to the ground state and excited states of ^{177}Hf

	$I_{\beta-}$ from g.s. of ^{177}Lu to levels of ^{177}Hf			
	J^π 7/2$^-$	J^π 9/2$^-$	J^π 11/2$^-$	J^π 9/2$^+$
Expt. I_γ NDS α_T	78.4^{3}	9.9^{3}	0.002^{7}	11.68^{14}
Expt. I_γ Expt. α_T	80.1^{2}	8.36^{1}	0.005^{8}	11.58^{13}
Adopted NDS	79.4	9.0	<0.012	11.61

Table 3: Beta intensities to the ground state and excited states of ^{175}Lu

	$I_{\beta-}$ from g.s. of ^{175}Yb to levels of ^{175}Lu			
	J^π 7/2$^+$	J^π 9/2$^+$	J^π 11/2$^+$	J^π 9/2$^-$
Expt. I_γ NDS α_T	72.0^{5}	7.2^{4}	0.018^{19}	20.8^{3}
Expt. I_γ Expt.α_T	72.5^{9}	6.6^{9}	0.04^{5}	21.0^{3}
Adopted NDS	72.9	6.7	<0.016	20.4

From Tables 2 and 3, it is clear that although the present results are of improved precision, the 1u beta branching intensity to the J^π =11/2 level vanishes within uncertainties in both decays. It can however be noted that the calculated values of $I_{\beta-}$ are nonzero. Further, the reasonable *log ft* values for these first forbidden unique transitions (Table 4) calculated with the LOGFT program help to speculate that there may be indeed weak beta feedings to these levels. In order to be able to obtain conclusive evidence, there is a need for better techniques in experimentation.

Table 4: Log ft values of β^- transitions in ^{177}Lu and ^{177}Yb decay

	$E_{\beta-}$ (keV)	$I_{\beta-}$	Log ft	
			NDS 2003	Present
^{177}Lu	498.3^{8}	78.4^{3}	6.697	6.642^{4}
	385.4^{8}	9.9^{3}	7.273	7.75^{3}
	248.6^{8}	0.002^{7}	>9.2	8.14^{9}
	177.0^{8}	11.68^{14}	6.083	6.322^{15}
^{175}Yb	470.1^{13}	72.0^{5}	6.426	6.43^{12}
	356.3^{13}	7.2^{4}	7.07	7.0^{3}
	218.6^{13}	0.018^{19}	>8.6	8.5
	73.8^{13}	20.8^{3}	4.44	4.4^{3}

References:

[1] B. Singh et al., Nucl. Data Sheets, 84 (1998) 487.
[2] Nuclear Data Sheets for A=167 to A=183.
[3] P. Alexander et al., Phys. Rev., 133 (1964) B284.
[4] A. J. Haverfield et al., Nucl. Phys., A94 (1967) 337.
[5] U. Schotzig et al., Appl. Radiat. Isot., 55 (2001) 89.
[6] M. Sainath, Ph.D. Thesis, SSSIHL, (1996)
[7] S.Deepa et al, Appl. Radiat.Isot, 69(2011)869
[8] S. Deepa et al., Ph.D thesis, SSSIHL, (2010)