LIMIT VALUES OF LOG-*ft* FOR FORBIDDEN β-TRANSITIONS AT ^{178}Ta DECAY

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UDC 539.163

The energies and the intensities of weak γ-transitions at 115 and 217 keV in the ^{178}Ta decay have been measured on a γ-spectrometer, with one of them being observed for the first time. The transitions are brought about by a discharge of the 8_2^- level at 1479 keV by means of the interband transition through the level 9_1^- at 1364 keV in ^{178}Hf. Estimations of the log-*ft* values for twice-forbidden β-transitions to levels 9_1^- at 1364 keV and 9_2^- at 1697 keV in ^{178}Hf have also been carried out for the first time.

According to the newest experimental data [1], ^{178}Ta decays ($I^\pi = 7^-$, $T_{1/2} = 2.36$ h) by means of electron capture onto the excited ^{178}Hf states with energies of 1147 and 1479 keV and with quantum characteristics ($I^\pi = 8^-, K = 8$) (see Fig. 1). The levels 8_1^- and 8_2^- in ^{178}Hf are strongly intermixed [2]. This follows from the close values of log-*ft* for ^{178m}Lu and ^{178}Ta decays to both those levels [3], as well as from the analysis of intraband $M1 + E2$ and $E2$ γ-transitions [4]. The value $g_k = 0.36$ calculated from experimental data falls between the theoretical value $g_k = 1.0$ for a two-quasiproton state and the value $g_k = -(0.005 \div 0.010)$ for a two-quasineutron one. The conclusions of works [3, 4] about the mixture of configurations are in good agreement. The lower level 8_1^- is predominantly two-quasineutron, n[514]$\downarrow$ + n[624] $\uparrow$, and the averaged value of the admixture of two-quasiproton state p[404] $\downarrow$ +p[514] $\uparrow$ amounts to (34 ± 4)%.

Since the mass difference between ^{178}Hf and ^{178}Ta equals $\Delta = (1910 \pm 100)$ keV [5], the decay of ^{178}Ta to levels of 1364 and 1697 keV of $I^\pi = 9^-$ rotational bands, which are constructed on 8_1^- and 8_2^- states, respectively, is possible. In this case, the transitions with energies of 217 and 218 keV must be observed. Exactly such a transition with an energy of 217 keV and an intensity of (0.3 ± 0.1)% was revealed in work [6] while studying the ^{178}Ta decay. But the basic question whether this transition is a result of the β-decay of the parent nucleus to the 1364-keV level or is supplied by the 115-keV interband transition remained unanswered. A technique of fabricating ^{178}Ta making use of the ^{181}Ta(γ,3n) reaction and a bremsstrahlung beam did not allow the authors of work [6] to obtain the isotope with a necessary purity degree, which prohibited them from carrying out more exact researches.

More promising is the fabrication of ^{178}Ta isotope in the (α,n) reaction by bombarding a lutetium target with α-particles with the energy $E_\alpha = 18$ MeV on a U-120 cyclotron; just this method was used in our work.

The γ-spectrum of ^{178}Ta was measured making use of a 5-cm^3 detector made up of highpure germanium and with a resolution of 490 eV at the 122-keV γ-line of ^{57}Co. Besides known γ-lines, the γ-lines at 115 and 217 keV we attribute to the ^{178}Ta decay were also observed in the spectrum. Notice that the γ-transition with an energy of 115 keV was registered for the first time. In Fig. 2, the section of the γ-spectrum, which contains the 213- and 217-keV γ-lines, is exhibited.

In total, three series of measurements of the ^{178}Ta γ-spectrum analogous to that shown in Fig. 2 were carried out. The spectra obtained were analyzed with the help of computer codes developed by us [7–9]. The final values of line energies and intensities were determined as weighed averages over three series of measurements. Either the weight or the scatter error was taken as the uncertainty of experimental values, depending on which of them was larger. The results of calculations are quoted in Table 1. The positions of γ-lines in the spectrum and the analysis of their intensities with respect to the half-life confirm that they are induced by the ^{178}Ta decay.

One can calculate the intensity ratios for the transitions from the 8_2^- level at 1479 keV to the levels 9_1^- at 1364 keV and 8_1^- at 1147 keV in ^{178}Hf. It is known [10] that, for the transitions from the I_i state of the rotational band K_i to various levels $I_f^1, I_f^2, \ldots$ of another rotational band K_f, the following relation is valid:

$$\frac{B(L, I_i \to I_f^1)}{B(L, I_i \to I_f^2)} = \frac{\langle I_i K_i; L K_f - K_i | I_f^1 K_f\rangle^2}{\langle I_i K_i; L K_f - K_i | I_f^2 K_f\rangle^2}.$$

That is, the reduced probabilities of transitions are referred to each other as the squares of relevant Clebsch–Gordan coefficients. Using the known relation between

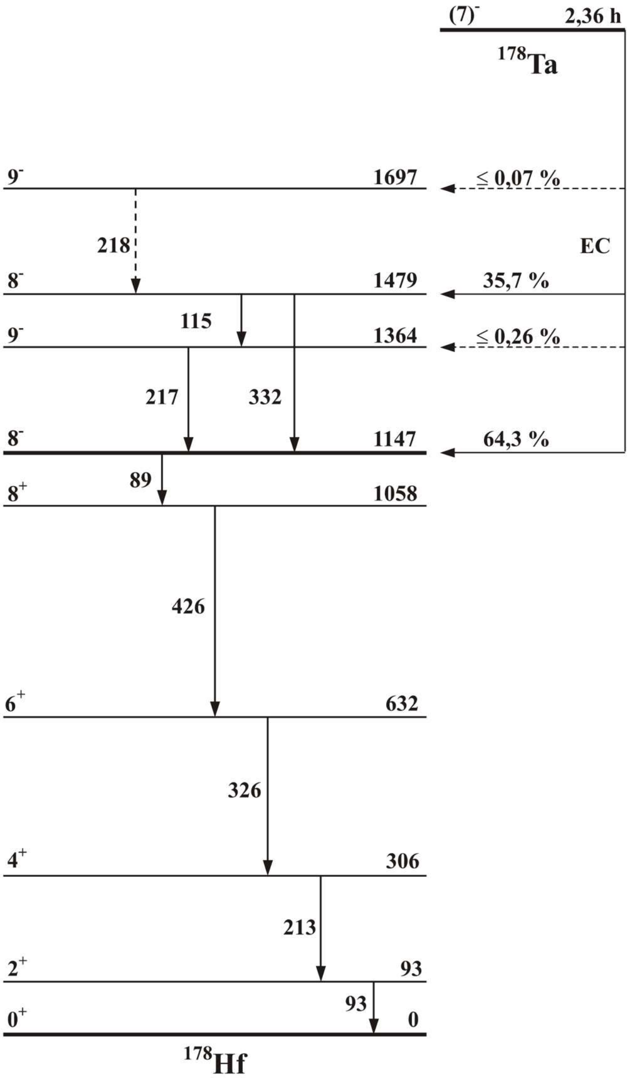

Fig. 1. Scheme of ^{178}Ta decay

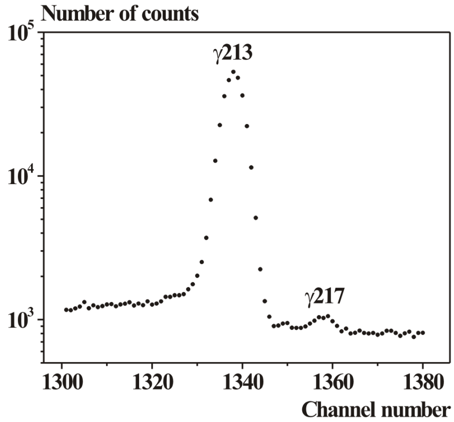

Fig. 2. Fragment of the γ-spectrum with γ-lines at 213 and 217 keV from the ^{178}Ta decay

the partial half-life and the reduced probability of radiative transition, we obtain

$$\frac{I_\gamma(115)}{I_\gamma(332)} = \frac{(115)^3}{(332)^3} \times \frac{\langle 8810|98\rangle^2}{\langle 8810|88\rangle^2} = 0.0052$$

for the ratio between the intensities of the γ-transitions concerned. The experimental value $I_\gamma(115)/I_\gamma(332) = 0.0029 \pm 0.0008$ agrees with the theoretical one within the limits of the doubled experimental error.

The 217-keV transition can be caused by both the interband 115-keV transition and the occupation from the β-decay immediately on the 9^-_1 level at 1364 keV in ^{178}Hf; the latter process should be considered responsible for the difference between the intensities of the 115- and 217-keV transitions.

The intensity of transitions were calculated on the basis of data concerning the intensities of γ-lines and presented in Table 1 by the formula

$$I_\gamma = I_\gamma(1 + \alpha_{\rm tot}),$$

where $\alpha_{\rm tot}$ is the total internal conversion coefficient (ICC) for the corresponding transition. The results of calculations, together with the data on the ICC, are given in Table 2. Note that the γ-transition at 115 keV is, most probably, of multipolarity $M1$. This follows from the analysis of the value of the mixing parameter $\delta^2(E2/M1)$ for interband transitions in ^{178}Hf. According to the data of work [2], for a similar γ-transition at 332 keV, the estimation of the mixing parameter gave the value $\delta^2(E2/M1) = 0.003$, which is in agreement with the experimental value $\delta^2(E2/M1) \leq 0.004$.

T a b l e 1. Energies and intensities of γ-lines excited at ^{178}Ta decay in the range 100–300 keV

Energy, keV	Intensity, rel. units
115.04 ± 0.08	0.0011 ± 0.0003
213.43 ± 0.01	100
216.58 ± 0.04	0.0046 ± 0.0004
218.5 ± 1.0	≤ 0.0006

T a b l e 2. Intensity of transitions in ^{178}Hf excited at ^{178}Ta decay in the range 100–300 keV

Arrangement of transitions in the decay scheme	Multi-polarity	ICC ($\alpha_{\rm tot}$)	Source	Intensity, % per decay
$8^-_2 \to 9^-_1$, 115 keV	$M1$	2.79	[11]	0.35 ± 0.09
$4^+_1 \to 2^+_1$, 213 keV	$E2$	0.234	[11]	100
$9^-_1 \to 8^-_1$, 217 keV	$E2 + M1$	0.289	[12]	$0.48 \pm 0,04$
$9^-_2 \to 8^-_2$, 218 keV	$M1$	0.452	[11]	≤ 0.07
$9^-_2 \to 8^-_2$, 218 keV	$E2$	0.223	[11]	≤ 0.06

T a b l e 3. Limit values of log-*ft* for β-transitions to levels 9_1^- at 1364 keV and 9_2^- at 1697 keV in ^{178}Hf at the ^{178}Ta decay

Level	E_ϵ, keV	log-*ft*
9_1^- 1364 keV	446	≥ 6.9
	546	≥ 7.1
	646	≥ 7.3
9_2^- 1697 keV	112	≥ 5.9
	212	≥ 6.7
	312	≥ 7.2

On the basis of data quoted in Table 2 and from the transition intensity balance, the limit values for the population of levels 9_1^- at 1364 keV and 9_2^- at 1697 keV in ^{178}Hf at the ^{178}Ta decay were obtained for the first time:

$I_\epsilon(9_1^-$ at 1364 keV$) \leq 0.26\%$ per decay and

$I_\epsilon(9_2^-$ at 1697 keV$) \leq 0.07\%$ per decay.

These results were used to calculate log-*ft* of transitions; for this purpose, we used the data of log-$(f_0^\epsilon + f_0^1)$ tables from work [13]. The results of calculations are presented in Table 3; they were also obtained for the first time. Since log-*ft* for the electron capture branches in the decay of ^{178}Ta (especially the 9_2^- level at 1697 keV) depend essentially on the transition energy, the calculations were executed for three values of energy within the limits of the experimental error of the $E_\epsilon^{\max}$ value.

Reliable experimental data on log-*ft* of doubly forbidden β-transitions are very scarce. In the range of nuclei with Z close to that of hafnium ($Z = 72$), we can quote the value log-$ft = 11.8$ for transitions at the ^{158}Tb decay ($I^\pi = 3^-$ and $T_{1/2} = 180$ years) to the level 1^- at 977 keV in ^{158}Gd [14] and log-$ft = 8.0$ at the ^{184}Ir decay ($I^\pi = 5^-$ and $T_{1/2} = 3.09$ h) on the 3^- level at 1544 keV in ^{184}Os [15]. The cited values of log-*ft* differ substantially, almost by factor of four. But even those data make it possible to draw conclusion that the accuracy of experiment must be increased at least by an order of magnitude for the observations of weak β-transitions at the ^{178}Ta decay to be reliable.

To summarize the results of our researches, it should be noted the following:

1) In the γ-spectrum of ^{178}Ta, in addition to the known γ-lines, two weak γ-lines at 115 and 217 keV are observed as well.

2) They are induced by a discharge of the 8_2^- level at 1479 keV by means of the interband transition through the 9_1^- level at 1364 keV in ^{178}Hf.

3) The value of the ratio between the experimental intensities of those γ-lines agrees with the result of theoretical calculations carried out in the framework of the generalized model of the nucleus.

4) The estimated limit values of log-*ft* for doubly forbidden β-transitions do not contradict the corresponding systematization in this nuclear range.

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Received 20.02.07.
Translated from Ukrainian by O.I. Voitenko

ГРАНИЧНІ ЗНАЧЕННЯ LOG-*ft* ЗАБОРОНЕНИХ β-ПЕРЕХОДІВ ІЗ РОЗПАДУ ^{178}Ta

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Р е з ю м е

На гамма-спектрометрі виміряно енергії та інтенсивності слабких γ-переходів 115 і 217 кеВ із розпаду ^{178}Ta, один з яких спостерігали вперше. Переходи є результатом розрядки рівня 8_2^- 1479 кеВ шляхом міжсмугового переходу через рівень 9_1^- 1364 кеВ ^{178}Hf. Вперше отримано також і оцінки величини log-*ft* подвійно заборонених β-переходів на рівні 9_1^- 1364 кеВ та 9_2^- 1697 кеВ ^{178}Hf.