Absolute Transition Probabilities from the 453.1 keV Level in 183 W

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ABSOLUTE TRANSITION PROBABILITIES FROM THE
453.1 keV LEVEL IN $^{183}$W

Sven G Malmskog

ABSTRACT

The half life of the 453.1 keV level in $^{183}$W has been measured by the delayed coincidence method to 18.4 ± 0.5 nsec. This determines twelve absolute M1 and E2 transition probabilities, out of which nine are K-forbidden. All transition probabilities are compared with the single particle estimate. The three K-allowed E2, $|\Delta K| = 2$ transition rates to the $\frac{1}{2}^-$ (510) rotational band are furthermore compared with the Nilsson model. An attempt to give a quantitative explanation of the observed transition rates has been made by including the effects from admixtures into the single particle wave functions.

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1. INTRODUCTION

Already in 1954 Murray et al. [1] made a careful study of the gamma and electron transitions in the deformed nucleus $^{183}\text{W}$. Two years later Kerman [2] showed that the level energies of the two well established $\frac{1}{2}^-$ - (510) and $\frac{3}{2}^-$ - (512) rotational bands could be accurately predicted by including a rotation-particle coupling correction (=RPC) to the well known adiabatic rotational energy formula. Recently the gamma ray energies and intensities in $^{183}\text{W}$ have been accurately remeasured by the curved crystal technique [3, 4] from the decay of $^{183}\text{Ta}$ (5 days). A corresponding high resolution measurement of the internal conversion electron lines of the transitions in $^{183}\text{W}$ has been given by Alexander and Hager [5]. From the measurement of L-sub shell conversion electron ratios these authors deduced the E2/M1 mixing ratios for the actual transitions. This new information has been used by Brockmeier et al. [6] for a critical test of the usefulness of the RPC scheme for fitting the experimental data from deformed odd A nuclei. Rowe [7] also has made an attempt to find out whether $|\Delta K| = 2$ bandmixing interactions play any role in the mixing of the $\frac{1}{2}^-$ and $\frac{3}{2}^-$ bands in $^{183}\text{W}$.

From the (d, p) reaction studies by Erskine [8] it now seems established that the 453.1 keV level in $^{183}\text{W}$ can be identified as the lowest level in the $\frac{7}{2}^-$ - (503) rotational band. This level is deexcited by seven transitions, all of them ending up on levels belonging to the $\frac{1}{2}^-$ - (510) and $\frac{3}{2}^-$ - (512) rotational bands. If the $\frac{7}{2}^-$ - (503) assignment is correct this means that all the M1 transitions from the 453.1 keV level are either once or twice K-forbidden, while the E2 transitions are allowed or once K-forbidden. From a survey of single particle transitions in odd A deformed nuclei [9] once K-forbidden E2 transitions are found to have a hindrance factor $F^{E2}_{W} = T_{1/2}^{1/2} \gamma^{\exp} / T_{1/2}^{1/2} \gamma$ (Weisskopf) of the order of $10^3$. The corresponding values for once and twice K-forbidden M1 transitions are $F^{M1}_{W} \sim 10^4$ and $F^{M1}_{W} \sim 10^5$ respectively. Using such estimates together with gamma and electron intensities for the transitions deexciting the 453.1 keV level its half life is found to be of the order of several nanoseconds. Such a half life can be measured by the delayed coincidence technique and the result offers a good test on the $\frac{7}{2}^-$ - (503) assignment of the 453.1 keV level. Furthermore...
the obtained absolute transition probabilities for the K-forbidden M1 and E2 transitions are to be compared with the Weisskopf estimate [10]. In the case of the E2, $|\Delta K| = 2$ transitions to the $\frac{3}{2}^-$ - (512) band the E2 transition probabilities are also compared with the Nilsson model [11].

2. EXPERIMENTAL PROCEDURE

2.1 Source preparation

Ten milligrams of spectroscopically pure tantalum metal was mechanically worked into a fine powder and pure alcohol was added. The smallest grains then form a suspension with the alcohol which was separated and dried in a small quartz bottle. This bottle was irradiated for two weeks in a neutron flux of $2 \times 10^{14}$ n/cm$^2$ sec. in which $^{183}$Ta was produced by the $^{181}$Ta $(2n,\gamma)$ $^{183}$Ta reaction. After activation alcohol was again added and the fine powder in the resulting suspension centrifuged onto a thin mylar backing. In this way several sources with 5 mm diameter and a thickness of 0.1 mg/cm$^2$ were prepared. A source strength of 1 $\mu$C was found to be adequate for the present coincidence measurement. From a Ge(Li)-gamma ray spectrum it was settled that the major part of the activity belonged to the decay of $^{183}$Ta (5 days) while the activity of $^{182}$Ta (115 days) immediately after activation was at least a factor of ten smaller.

2.2 Half life measurement

$^{183}$Ta is a $\beta^-$ emitting nucleus with a predominant 615 keV branch (87 %) to the 453.1 keV $7/2^- 7/2^-$ - (503) excited level in $^{183}$W (fig. 1) [12]. This level is then deexcited by seven transitions ending up on the well known $1/2^- - (510)$ and $3/2^- - (512)$ rotational bands. Some of these transitions together with the feeding $\beta^-$ branch were used for the determination of the half life of the 453.1 keV level. The principal instrumentation in this investigation has been an electron-electron coincidence spectrometer very similar to the one described earlier by Gerholm and Lindskog [13]. The time to pulse height converter used in this experiment utilizes the internal sweep of an oscilloscope and is a construction very similar to the one described by Thieberger [14]. To increase the coincidence efficiency we preferred to detect the exciting 615 keV $\beta^-$
transition in a bare Naton 136 plastic scintillator placed 3 mm from the source. The other channel consisted of one lens, set to 3% energy resolution, where different conversion lines were focussed onto a specially shaped Naton 136 plastic scintillator [15] optically coupled to the photomultiplier 56 AVP. From a single electron spectrum it was seen that, of the transitions leaving the 453.1 keV level, the 354.0 K electron transition was fully resolved while the 244.3 K and the 246.1 K transitions formed an unresolved group. The other four transitions were either too weak or were strongly mixed with other transitions with approximately the same electron energies.

Throughout the actual delayed coincidence measurement we accepted the $\beta^-$ continuum between 400 and 600 keV as start pulses which were fed to the external sweep trigger of a Tectronix 545 oscilloscope. The 354.0 K or 246.1 K electrons were used as stop pulses and fed to the special sampling plug in unit [14]. 1000 nsec was chosen as full time sweep time (the fastest sweep time of this oscilloscope). The linear output pulses were analysed by a Nuclear Data 256 multichannel analyser. For the time calibration we used the internal delay unit of the oscilloscope itself, which in turn was compared with a 10 Megacycle crystal oscillator. We also measured the delay of the well known 482 keV level in $^{181}$Ta for which we found $T_{1/2} = (10.5 \pm 0.3)$ nsec, in good agreement with previous investigations [16]. A typical decay curve from the $\beta^-$-246.1 K cascade is given in fig. 1. The picture shows an essentially delayed decay curve with a small prompt contribution mainly from $\gamma-\beta^-$ coincidences in the decay of $^{182}$Ta. By putting an Al absorber in front of the bare plastic crystal this $\gamma-\beta^-$ disturbance was measured and corrected for by subtraction. The remaining curve was analysed by a least squares fit to a function consisting of a single exponential decay plus a constant background. The following results were obtained:

$\beta^-(400 - 600 \text{ keV}) - 246.1 \text{ K (4 measurements)} T_{1/2} = 18.3 \pm 0.5 \text{ nsec}$

$\beta^-(400 - 600 \text{ keV}) - 354.0 \text{ K (3 measurements)} T_{1/2} = 18.6 \pm 0.7 \text{ nsec}$

From these measurements we conclude that the half-life of the 453.1 keV level in $^{183}$W is $T_{1/2} = 18.4 \pm 0.5 \text{ nsec.}$
3. DISCUSSION

The presently known relevant experimental information on the decay of the 453.1 keV level in $^{183}W$ is summarized in table 1. Out of the twelve M1 and E2 components in this decay nine are K-forbidden, while the three E2 components to the $\frac{3}{2}^{-} - (512)$ rotational band are K-allowed but asymptotically forbidden (they require a spin flip). In column 9 all these absolute transition probabilities are given in the single particle units (Weisskopf estimate). The tabulated hindrance factor $F_w$ is defined by $T_{1/2}^{(\gamma)}(\text{exp})/T_{1/2}^{(\gamma)}(s.p.)$ where $T_{1/2}^{(\gamma)}$ is the partial gamma ray transition probability. The $F_w$ factors for the three E2, $\Delta K = 2$ transitions show that these are all retarded by more than a factor of ten, which reflects their asymptotically forbidden character. Such a hindrance is furthermore expected as due to pairing effects. These E2 transitions are, however, enhanced as compared with the Nilsson model. In the light of earlier findings from other E2, $|\Delta K| = 2$ transitions [9] such enhanced E2 transitions are quite understandable. Fig. 2 shows the $F_N$ factors for such E2 transitions plotted as a function of the energy difference between the decaying state and the nearest state capable of giving a $|\Delta K| = 2$ mixing component, e.g. the $\frac{5}{2}^{+} - \frac{7}{2}^{-} - (512)$ and the $\frac{5}{2}^{+} - (521)$ states in $^{169}$Yb, $^{173}$Yb and $^{175}$Hf. The figure shows that there is a general trend for the $F_N$ factor to increase as the above mentioned energy difference increases. In $^{183}W$ the $\frac{7}{2}^{+} - (503)$ and the $\frac{7}{2}^{+} - (512)$ states are only 41 keV apart, which gives an opportunity for a strong mixing and thus enhanced E2, $|\Delta K| = 2$ transitions are expected. This effect is interpreted as due to admixtures caused by a $|\Delta K| = 2$ perturbing interaction.

Another possibility of studying these coupling effects occurs in the case of the K-forbidden transitions, which according to the Nilsson model are strictly forbidden. That such transitions actually take place can be understood in the light of admixtures of intrinsic states. In the case of the $\frac{1}{2}^{-}$ and $\frac{3}{2}^{-}$ bands in $^{183}W$ they are known to have a mutual mixing of the order of 5 - 20 per cent due to Coriolis coupling [6]. The once K-forbidden E2 transitions to the $\frac{1}{2}^{-}$ band are thus understood as E2 transitions between the $\frac{7}{2}^{+}$ band and the admixed $\frac{3}{2}^{-}$ component into the $\frac{1}{2}^{-}$ band. Taking into account the approximate ten per cent mixing, such once K-forbidden E2 transitions are expected to be slowed down an order of magnitude as compared with the corresponding K-allowed transitions.
In the case of K-forbidden M1 transitions no effect of such a direct mixing by Coriolis interaction occurs since $|\Delta K| = 2$ or 3. Furthermore there is no low-lying $\frac{5}{2}^+$ band which can be appreciably mixed into the $\frac{7}{2}^-$ and $\frac{3}{2}^-$ bands. One may therefore in this case assume that a direct $|\Delta K| = 2$ band-mixing can play a role in explaining the K-forbidden M1 rates from the $\frac{7}{2}^-$ (503) level. In the case of the once K-forbidden M1 transitions to the $\frac{3}{2}^-$ band such a direct $|\Delta K| = 2$ mixing should be expected to give an amplitude contribution of the order of per cent and therefore a corresponding retardation of a factor of one hundred as compared to the corresponding allowed M1 transitions. For the twice K-forbidden M1 transitions to the $\frac{1}{2}^+$ band these M1 transitions are understood to take place via the $K = \frac{3}{2}^-$ component mixed into the $\frac{7}{2}^-$ band by some $|\Delta K| = 2$ interaction. The other contributing terms will be of less importance as they require both a $|\Delta K| = 2$ and a Coriolis mixing, which will slow down these transition rates further by a factor of 5 - 20 depending on the magnitude of the Coriolis mixing between the $\frac{1}{2}^+$ and $\frac{3}{2}^-$ bands.

It thus seems possible by such simple arguments to give a quantitative picture of the different absolute transition probabilities from the $\frac{7}{2}^-$ (503), 453.1 keV level in $^{183}\text{W}$, which is in rough agreement with the experimental findings. To get a better understanding of the different transition rates, however, a more detailed calculation regarding the $|\Delta K| = 2$ band mixing should be worthwhile.

ACKNOWLEDGEMENT

The author is indebted to Dr. Sven Wahlborn for his kind interest in this work.
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<th>Final state</th>
<th>Multipolarity</th>
<th>Relative $N_{\gamma}$</th>
<th>Relative $N_e$</th>
<th>$T_{1/2}^{\text{exp}}$ in sec.</th>
<th>$F_W$</th>
<th>$F_N$</th>
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<td>$\gamma$ (503)</td>
<td>$^{3}\frac{1}{2}^{-}$ (510)</td>
<td>$^{3}\frac{1}{2}^{-}$ (510)</td>
<td>E2</td>
<td>1.9±0.1</td>
<td>0.08</td>
<td>(3.3±0.3)x10^{-6}</td>
<td>(4.2±0.4)x10^{-3}</td>
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<td>354.0</td>
<td>$^{5}\frac{1}{2}^{-}$ (510)</td>
<td>$^{5}\frac{1}{2}^{-}$ (510)</td>
<td>M1</td>
<td>39.7±1.3</td>
<td>6.1</td>
<td>(1.6±0.1)x10^{-7}</td>
<td>(3.2±0.3)x10^{-5}</td>
<td>2 K-forb.</td>
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<td></td>
<td></td>
<td></td>
<td>E2</td>
<td>2.9±2.9</td>
<td>0.1</td>
<td>$\geq1.1x10^{-6}$</td>
<td>$\geq6.8x10^{2}$</td>
<td>1 K-forb.</td>
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<td>246.1</td>
<td>$^{7}\frac{1}{2}^{-}$ (510)</td>
<td>$^{7}\frac{1}{2}^{-}$ (510)</td>
<td>M1</td>
<td>99.7±3.0</td>
<td>40.0</td>
<td>(6.4±0.5)x10^{-8}</td>
<td>(4.2±0.3)x10^{-4}</td>
<td>2 K-forb.</td>
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<td></td>
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<td></td>
<td>E2</td>
<td>0.3±0.3</td>
<td>0.04</td>
<td>$\geq1.1x10^{-5}$</td>
<td>$\geq1.1x10^{3}$</td>
<td>1 K-forb.</td>
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<td>244.3</td>
<td>$^{3}\frac{3}{2}^{-}$ (512)</td>
<td>$^{3}\frac{3}{2}^{-}$ (512)</td>
<td>E2</td>
<td>32.0±1.0</td>
<td>5.8</td>
<td>(2.0±0.2)x10^{-7}</td>
<td>19±2</td>
<td>(6.5±0.7)x10^{-2}</td>
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<td>161.4</td>
<td>$^{5}\frac{3}{2}^{-}$ (512)</td>
<td>$^{5}\frac{3}{2}^{-}$ (512)</td>
<td>M1</td>
<td>32.3±1.5</td>
<td>41.0</td>
<td>(2.0±0.2)x10^{-7}</td>
<td>(3.9±0.4)x10^{-4}</td>
<td>1 K-forb.</td>
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<td></td>
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<td></td>
<td>E2</td>
<td>1.0±0.7</td>
<td>0.9</td>
<td>(6.4±4.8)x10^{-6}</td>
<td>78±54</td>
<td>(6.5±4.7)x10^{-1}</td>
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<td>144.1</td>
<td>$^{9}\frac{1}{2}^{-}$ (510)</td>
<td>$^{9}\frac{1}{2}^{-}$ (510)</td>
<td>M1</td>
<td>9.3±0.5</td>
<td>16.0</td>
<td>(6.8±0.7)x10^{-7}</td>
<td>(9.0±0.9)x10^{-4}</td>
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<td></td>
<td>E2</td>
<td>0.1±0.1</td>
<td>0.01</td>
<td>$\geq3.2x10^{-5}$</td>
<td>$\geq2.0x10^{2}$</td>
<td>1 K-forb.</td>
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<td>41.0</td>
<td>$^{7}\frac{3}{2}^{-}$ (512)</td>
<td>$^{7}\frac{3}{2}^{-}$ (512)</td>
<td>M1</td>
<td>1.7±0.2</td>
<td>19.8</td>
<td>(3.8±0.6)x10^{-6}</td>
<td>(1.2±0.2)x10^{-4}</td>
<td>1 K-forb.</td>
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<tr>
<td></td>
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<td></td>
<td>E2</td>
<td>(30±8)x10^{-4}</td>
<td>0.7</td>
<td>(2.1±0.6)x10^{-3}</td>
<td>28±8</td>
<td>(2.5±0.8)x10^{-2}</td>
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a) Gamma ray intensities recommended in Journal of Nuclear Data, Vol. IB, Feb. 1966. The $N_{\gamma}$ and $N_e$ intensities are normalized to give $N_{\gamma}$ for the 246.1 keV transition to 100.

b) Electron intensities taken from ref. 1 and 5.

c) Weisskopf estimate taken from Wapstra et al., Nuclear spectroscopy tables, Amsterdam 1959, with statistical factor = 1.

d) Calculated with pure Nilsson wave functions from ref. 11. The deformation was taken as $\eta = 4$. 
Fig. 1. Delayed coincidence curve taken between the 615 keV beta continuum and the 246 K conversion line in the decay of $^{183}_{73}$Ta, giving $T_{1/2} = 18.4 \pm 0.5$ nsec for the 453.08 keV level in $^{183}_{74}$W. The inset shows the deexcitation of this 453.08 keV level. The dashed curve illustrates the decay of the well known 10.5 nsec isomeric level in $^{181}_{75}$Ta.
The hindrance factors $F_N$ of $E2, |\Delta K| = 2$ transitions are shown as a function of the energy difference between the two states with the same angular momentum which mix the two rotational band. See further description in the text. The following symbols are used: $\blacklozenge$ proton transitions, $\bigcirc$ neutron transitions. A: transitions from $I_i = K_i$ to $I_f = K_f$, B: $I_i = K_i$ to $I_f = K_f + 1$, C: $I_i = K_i$ to $I_f = K_f + 2$ and E: $I_i = K_i + 1$ to $I_f = K_f + 1$. The two values of $F_N$ for the proton transitions correspond to the hindrance factors obtained with (the upper) and without (the lower) effective charge correction. Most of the information given in this figure is taken from reference 9.
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