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The ground state spin of $^{180}$Ta is not $8^+$

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Abstract. — Experimental (p, d) cross-sections are compared with calculations using Nilsson wave functions and the DWBA in order to locate the members of the low lying (1+, 1) and (8+, 8) rotational bands in $^{180}$Ta.

Until recently [1] only two levels have been observed in $^{180}$Ta, both isomers. The long-lived isomer, considered as the ground state, has $T_{1/2} > 10^{13}$ y [2], [3]. The other level with $T_{1/2} = 8.15$ h. has been previously located at 212 keV [4], [5] and recently at 32 keV [6]. The log $f$ values for the decay of the latter level to the 0+ and 2+ first excited states of $^{180}$W and $^{180}$Hf, are consistent with allowed or possibly first forbidden transitions. Asaro et al. [7] suggested values of $I^*$, $K^* = 1^-, 0$ and $I^*, K = 8^+, 8$ or 9-, 9 respectively for the short-lived (SLI) and long-lived (LLI) isomers.

Experimental observations by Gallagher et al. [8] on the SLI decay exclude the (1-, 0) assignment which arises from the coupling of 9/2- [514]p with 9/2+ [624]n with antiparallel spins ($\Sigma = 0$). The same experiment is consistent with the (1+, 1) configuration. Due to this very small energy difference the (9-, 9) as well as the (8+, 8) states could be the LLI. However in all other known odd-odd tantalum nuclei the ground state proton configuration is due to the coupling with parallel intrinsic spins of the unpaired neutrons.

If one adopts (1+, 1) for the SLI, the identification of the (8+, 8) member of this configuration with a lower lying state would violate the Gallagher-Moszkowski empirical rule (G-M rule) [9]. This rule states that the member of the doublet corresponding to parallel intrinsic spins of the unpaired nucleons has the lowest excitation. As far as is known, such a violation has been observed once in $^{166}$Ho where the ground state is $(0^-, 0)$ ($\Sigma_p + \Sigma_n = \Sigma = 0$) but only 5 keV below the $(7^-, 7)$ member ($\Sigma = 1$). It must be pointed out that in this case the long-lived isomer ($T_{1/2} > 1.2 \times 10^3$ y) is not the ground state which has $T_{1/2} = 27$ h. [10].

The doublet $K_x = 1^+$ and $K_x = 8^+$ from the configuration $\{ 7/2^+ [404]_p, 9/2^+ [624]_n \}$ has been observed in $^{176}$Lu and the (8+, 8) member lies 206 keV above the (1+, 1) again in agreement with the G-M rule [1].

The aim of this letter is to propose, with the help of new experimental data, an alternative to the low lying level scheme of $^{180}$Ta and to try to explain some of the contradictions outlined above.

The $^{180}$Ta nucleus has been investigated by the $^{181}$Ta(p, d)$^{180}$Ta reaction at $E_p = 19$ MeV using a magnetic spectrograph. The experimental procedure is described elsewhere [1].

Assuming a direct transfer mechanism, the observed excited states in the low energy region result from the coupling of the transferred neutron with the unpaired proton of the target ground state e.g. 7/2$^+$ [404]$_p$. The lowest neutron state is 9/2$^+$ [624]$_n$, ground state configuration of $^{177}$Yb, $^{179}$Hf and $^{181}$W, all isotones of $^{180}$Ta. It is this configuration which produces the Gallagher-Moszkowski doublet with $K^* = 1^+$ and

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Among other possible neutron states below 900 keV excitation the $9/2^+$ [624 T] is the only one with even parity [12]. The expected transfers to the members of the two bands built with this neutron state are $l = 4, j = 9/2$ ($C^0 = 0.126$) and $l = 6, j = 13/2$ ($C^0 = 0.98$). We exclude the $l = 6, j = 11/2$ transfer because the corresponding $C^0$ is negligible.

For the two first members of the $1^+$ band, the only allowed transfer is $l = 4$ with a relatively small intensity. The $8^+$ band, in contrast is excited by $l = 4$ and strongly so by $l = 6$. Referring to the energy of the observed lowest level, taken to zero, we see that the angular distributions of the levels at 0 and 41 keV are well fitted by a pure $l = 4$ transfer (Fig. 1a).

The two first levels are observed with a large experimental error, but the theoretical absolute cross-sections represent 60% of the observed cross-sections. In contrast the $(8^+, 8)$ absolute theoretical cross-section is more than two times too large to fit either of these levels. Furthermore the $(3^+, 1)$ member of the $1^+$ band is easily identified with the level at 106 keV by taking an inertia parameter $h^2/2J = 10.5$ keV [1]. Both the angular distribution and absolute cross-sections are fitted (Table I; Fig. 1a).

In a previous paper [1], we have shown that the $(4^+, 1)$ member of this band is a part of the experimental multiplet at 173 keV including the $(8^+, 8)$ state. An additional proof of the location of this member of the G-M doublet is given by the state observed at 366 keV which is identified as the $(9^+, 8)$. Its angular distribution is $l = 6$ as expected (see Fig. 1b). This is the only $l = 6$ angular distribution in this energy region and a good agreement between theoretical and experimental cross-sections is found (Table I). This identification leads to the location of the $(8^+, 8)$ band head at 177 keV in good agreement with a previous identification based essentially on cross-section considerations [1].

The $(5^+, 1)$ state is expected at 294 keV, with an $l = 6$ angular distribution. Experimentally one observes a level at 303 keV showing an angular distribution dominated by $l = 6$ (see Fig. 1b). The major part of the measured cross-section comes from the $(5^+, 1)$ state.

Hence the members of the $(1^+, 1)$ band have been identified with a good degree of confidence up to $(5^+, 1)$. The $(8^+, 8)$ member of the G-M doublet is shown to be above the $(1^+, 1)$ level. In addition to arguments quoted in the introduction it has been shown that if the lowest level observed in our experiment was assigned $(8^+, 8)$ it would be impossible to explain the energy and transfer cross-sections of other low lying observed levels. Finally, the proposed level scheme leads to a G-M term of the $V_{np}$ residual interaction of $A = -104$ keV in very good agreement

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Table I. — Experimental and theoretical cross-sections for members of the $(1^+, 1)$ and $(8^+, 8)$ bands in $^{180}$Ta excited in the $^{181}$Ta(p, d)$^{180}$Ta reaction.

<table>
<thead>
<tr>
<th>$I^*, K$</th>
<th>Energy (keV)</th>
<th>Experiment ($\sigma (50^\circ)$)</th>
<th>Theory ($\sigma (65^\circ)$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1^+, 1$</td>
<td>4.5 ± 1.0 ($^\circ$)</td>
<td>2.1 ± 0.9</td>
<td>2.50 ($^\circ$)</td>
</tr>
<tr>
<td>$2^+, 1$</td>
<td>5.0 ± 1.0 ($^\circ$)</td>
<td>2.1 ± 0.9</td>
<td>2.64 ($^\circ$)</td>
</tr>
<tr>
<td>$3^+, 1$</td>
<td>6.3 ± 1.7</td>
<td>7.0 ± 2.0</td>
<td>3.56</td>
</tr>
<tr>
<td>$4^+, 1$</td>
<td>34.5 ± 5.5</td>
<td>43.5 ± 3.6</td>
<td>6.03</td>
</tr>
<tr>
<td>$5^+, 1$</td>
<td>8.2 ± 2.2</td>
<td>16.0 ± 3.0</td>
<td>12.06</td>
</tr>
<tr>
<td>$8^+, 8$</td>
<td>34.5 ± 5.5</td>
<td>43.5 ± 6.4</td>
<td>10.07</td>
</tr>
<tr>
<td>$9^+, 8$</td>
<td>11.0 ± 4.0</td>
<td>24.5 ± 5.0</td>
<td>8.76</td>
</tr>
</tbody>
</table>

(*) Unresolved in experiment (see Ref. [1]).

(*) Given by $E(I^*, K) = E(K^*, K) + h^2/2 \not K^2\not H + 1 - K^2$ with $h^2/2 \not = 10.5$ keV.

(*) Cross-section at $\theta_{mis} = 50^\circ$. 

Fig. 1. — Angular distributions of states in $^{180}$Ta excited by the $^{181}$Ta(p, d)$^{180}$Ta reaction at $E_p = 19$ MeV. Solid lines are theoretical calculations using Nilsson wave functions and DWBA:

(a) Members of the $(1^+, 1)$ band; (b) Members of the $(8^+, 8)$ band.
THE GROUND STATE SPIN OF $^{180}$Ta IS NOT $8^+$
with calculations of Boisson et al. for this configuration [13].

There are many uncertainties in previous works on $^{180}$Ta. It was first admitted that the SLI is located above the LLI. But from more recent data [14] and from neutron binding energy systematics [15] it cannot be excluded that the lower excited state is the SLI. The facts which appear to be well established are that the SLI is a $(1^+, 1)$ state and the LLI a state with $K \geq 8$, although experimental results on the decay of the long-lived isomer are scarce [2], [3]. From the present work it is established that the $(1^+, 1)$ state with configuration $\{7/2^+ \ [404]_p, 9/2^+ \ [624]_n \}$ is excited at lower energy than the $(8^+, 8)$ which belongs to the same G-M doublet.

If the LLI is the $(8^+, 8)$ state then it must be an excited state at least at 180 keV.

The other state of high spin, the $(9^-, 9)$ of configuration $\{9/2^- \ [514]_p, 9/2^+ \ [624]_n \}$ which cannot be excited in this neutron transfer reaction, could be the long-lived isomer and be above or below the $(1^+, 1)$. Furthermore we cannot completely exclude another configuration for the $(1^+, 1)$ that is $\{9/2^- \ [514]_p, 7/2^- \ [514]_n \}$ also unobservable in a pick-up from $^{181}$Ta. The $\beta^-$ and E.C. decay properties measured experimentally [8] are compatible with such a configuration but the corresponding $1^+$ state is expected above the $(1^+, 1)$ band head identified here.

From these results one concludes that if the long-lived isomer is the lower excited state and if the short-lived isomer is the $(1^+, 1)$ identified here, then the $(9^-, 9)$ state is the only reasonable candidate for the long-lived isomer. Finally, concerning the ground state spin of $^{180}$Ta only two assignments are possible, either $(1^+, 1)$ from $\{7/2^+ \ [404]_p, 9/2^+ \ [624]_n \}$ or $(9^-, 9)$ from $\{9/2^- \ [514]_p, 9/2^- \ [624]_n \}$. In any case the spin $(8^+, 8)$ is excluded. The excitation of $^{180}$Ta via a proton transfer reaction, ($^3$He, d) or ($\alpha$, 1) would help to choose between $1^+$ or $9^-$. 

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References


