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

E. Warde (*), R. Seltz, G. Costa, D. Magnac and C. Gerardin

C.R.N. and U.L.P., Basses Energies, 67037 Strasbourg, France

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Résumé. — Des membres des bandes rotationnelles $(1^+, 1)$ et $(8^+, 8)$ ont été identifiés dans la région de faible excitation de ^{180}Ta par une comparaison des sections efficaces de transfert (p, d) avec des calculs en DWBA, utilisant des fonctions d'onde de Nilsson.

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 ft 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^π , $K = 1^-, 0$ and I^π , $K = 8^+, 8$ 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 $9/2^- [514 \uparrow]_p$ with $9/2^+ [624 \uparrow]_n$ with antiparallel spins ($\Sigma = 0$). The same experiment is consistent with $(1^+, 1)$ explained as due to the coupling of $7/2^+ [404 \downarrow]_p$ with the $9/2^+ [624 \uparrow]_n$ with parallel intrinsic spins ($\Sigma = 1$). The two configurations mentioned above give rise also to states with $(9^-, 9) \Sigma = 1$ and $(8^+, 8) \Sigma = 0$. Both of these spins have been proposed for the LLI and the experimental study has not solved this ambiguity. The intrinsic proton state $9/2^- [514 \uparrow]_p$ of the $(9^-, 9)$ configuration in ^{180}Ta appears in ^{181}Ta at 6 keV above the $7/2^+ [404 \downarrow]_p$ ground state which corresponds to the $(8^+, 8)$ 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 $7/2^+ [404 \downarrow]_p$ with a neutron state.

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 $K_\pi = 1^+$ and $K_\pi = 8^+$ from the configuration $\{ 7/2^+ [404 \downarrow]_p, 9/2^+ [624 \uparrow]_n \}$ 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 $^{181}\text{Ta}(p, d)^{180}\text{Ta}$ 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. $7/2^+ [404 \downarrow]_p$. The lowest neutron state is $9/2^+ [624 \uparrow]_n$, 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 $K_\pi^\pm = 1^+$ and

(*) On leave from University of Lattakia (Syria).

$K_{\pi}^{\pi} = 8^{+}$. Among other possible neutron states below 900 keV excitation the $9/2^{+}$ [624 ↑] is the only one with even parity [12]. The expected transfers to the members of the two bands built with this neutron state are $l = 4, j = 9/2$ ($C_{ji}^g = 0.126$) and $l = 6, j = 13/2$ ($C_{ji}^g = 0.98$). We exclude the $l = 6, j = 11/2$ transfer because the corresponding C_{ji}^g 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).

Fig. 1. — Angular distributions of states in ^{180}Ta excited by the $^{181}\text{Ta}(p, d)^{180}\text{Ta}$ 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 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 $\hbar^2/2J = 10.5$ 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

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

I^{π}, K	Energy (keV)		Cross-section ($\mu\text{b/sr}$)			
	Exp.	Theory (^b)	Experiment		Theory	
			$\sigma(45^{\circ})$	$\sigma(65^{\circ})$	$\sigma(45^{\circ})$	$\sigma(65^{\circ})$
$1^{+}, 1$	0	0	4.5 ± 1.0 (^c)	2.1 ± 0.9	2.50 (^c)	1.48
$2^{+}, 1$	41	42	5.0 ± 1.0 (^c)	2.1 ± 0.9	2.64 (^c)	1.57
$3^{+}, 1$	106	105	6.3 ± 1.7	7.0 ± 2.0	3.86	5.26
$4^{+}, 1$ (^a)	173	189	34.5 ± 5.5	43.5 ± 6.4	5.93	10.68
$5^{+}, 1$	302	294	8.2 ± 2.2	16.0 ± 3.0	6.10	12.06
$8^{+}, 8$ (^a)	173	177	34.5 ± 5.5	43.5 ± 6.4	10.07	9.87
$9^{+}, 8$	366	366	11.0 ± 4.0	24.5 ± 5.0	8.76	18.20

(^a) Unresolved in experiment (see Ref. [1]).

(^b) Given by $E(I^{\pi}, K) = E(K^{\pi}, K) + \hbar^2/2J [I(I+1) - K^2]$ with $\hbar^2/2J = 10.5$ keV.

(^c) Cross-section at $\theta_{\text{lab}} = 50^{\circ}$.

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 $\{7/2^+ [404 \downarrow]_p, 9/2^+ [624 \uparrow]_n\}$ 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 $\{9/2^- [514 \uparrow]_p, 9/2^+ [624 \uparrow]_n\}$ 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 $\{9/2^- [514 \uparrow]_p, 7/2^- [514 \downarrow]_n\}$ also unobservable in a pick-up from ^{181}Ta . The β^- 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 $\{7/2^+ [404 \downarrow]_p, 9/2^+ [624 \uparrow]_n\}$ or $(9^-, 9)$ from $\{9/2^- [514 \uparrow]_p, 9/2^+ [624 \uparrow]_n\}$. In any case the spin $(8^+, 8)$ is excluded. The excitation of ^{180}Ta via a proton transfer reaction, $(^3\text{He}, d)$ or (α, t) would help to choose between 1^+ or 9^- .

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