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# $\nu i_{13/2}$ and $\nu h_{9/2}$ Isomers in Odd-A Pt Nuclei*

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$13/2^+$ isomers with half-lives of 311±15, 143±5 and 95±5 μs in $^{187}$Pt, $^{189}$Pt and $^{191}$Pt, respectively, have been observed in (α,3nγ) reactions on isotopically enriched Os targets. Isomeric decay schemes based on the present measurements and on $^{189}$Au and $^{191}$Au decay data are presented. It is proposed that the $^{187, 189, 191}$Pt $13/2^+$ isomers de-excite by M2 transitions to $9/2^-$ intrinsic states of $\nu h_{9/2}$ character. In A ≥ 193 Pt nuclei the corresponding $9/2^-$ states must lie above the known $\nu i_{13/2}$ isomers, which have much longer half-lives.

NUCLEAR REACTIONS $^{186, 188, 190, 192}$Os(α,3nγ), E = 30-50 MeV, enriched targets; measured σ(E), $E_\gamma$, $I_\gamma$, γ-γ coin, σ(θ)γ, $T_{1/2}$, deduced $^{187}$Pt, $^{189}$Pt, $^{191}$Pt isomeric decay schemes, J, π.

## I. INTRODUCTION

In a recent study[1] of the high-spin level systematics of $^{186-194}$Pt by (α,xnγ) reactions on isotopically enriched Os targets, we identified decoupled $\nu i_{13/2}$ bands in the four odd-A nuclei $^{187}$Pt, $^{189}$Pt, $^{191}$Pt and $^{193}$Pt. The $13/2^+$ bandheads which were observed to be very strongly populated in the (α,3n) reactions are low-lying isomers and not the ground states of these nuclei. The present paper describes the properties and modes of de-excitation of these $13/2^+$ isomers. Very recently, the ground state spins of $^{187}$Pt, $^{189}$Pt and $^{191}$Pt have been determined to be 3/2 by the atomic beam magnetic resonance method[2].

In $^{193}$Pt and $^{195}$Pt, $13/2^+$ M4 isomers with half-lives of 4.3 and 4.2 days, respectively, have been known for several years[3]. No isomers with comparable half-lives have been found in the lighter odd-A Pt nuclei, but there have been reports of shorter lived isomers which are pertinent to the present investigation. In the Ir(p,2n) reaction, Conlon[4] identified a 107-μs $^{191}$Pt isomer de-exciting by a 91-keV E2 transition. In similar proton bombardments of natural iridium, Fraser and Moore[5] observed γ-rays of 167 and 90 keV decaying with half-lives of 145 and 95 μs, respectively, and tentatively assigned them to new $^{190}$Pt and $^{192}$Pt isomers. These assignments are shown on the most recent Chart of the Nuclides[6]. In studies of the radioactive decay of high-spin $^{189m}$Au, the ISOLDE collaboration[7] identified a $^{189}$Pt isomer decaying by a 167-keV E2 transition with a half-life of 464 ns.

## II. EXPERIMENTAL PROCEDURE AND ANALYSIS

The experimental methods used were very similar to those described in the

preceding paper[8]. Targets of isotopically enriched $^{186}$Os(62%), $^{188}$Os(87%), $^{190}$Os(95%) and $^{192}$Os(98%) were bombarded with 30-50 MeV α-particles from the Michigan State University cyclotron and γ-ray singles, γ-γ coincidence, angular distribution and lifetime measurements were performed. Isotopic assignments of individual γ-rays to $^{187}$Pt, $^{189}$Pt, $^{191}$Pt and $^{193}$Pt were based primarily on excitation function determinations. When the γ-γ coincidence data for all four nuclei had been completely analysed, no strong γ-rays of $^{193}$Pt remained unplaced in the level scheme. However, intense γ-rays of 91.1, 166.7 and 117.3 keV which the excitation function measurements quite clearly showed to be due to $^{191}$Pt, $^{189}$Pt and $^{187}$Pt, respectively, remained unplaced. These γ-rays did not appear in the prompt coincidence spectra, their angular distributions were isotropic and, in beam-sweeping lifetime measurements, no decay of the lines was detectable during a 500-ns period. Therefore longer lifetime measurements were undertaken using a beam pulsing system which greatly extended the range of measurable lifetimes. For the isomers under study here, it was found suitable to allow beam on target every millisecond for 200 μs, followed by an 800-μs beam-off period. In Fig. 1, the decay data obtained and the half-lives determined for the three isomers are shown.

It is clear from these results that the 145- and 95-μs activities reported by Fraser and Moore[5] should be reassigned to $^{189}$Pt and $^{191}$Pt, respectively. In addition, the 95-μs $^{191}$Pt 91-keV γ-ray activity is obviously the same as the 107-μs $^{191}$Pt activity reported by Conlon[4].

At first, the 143-μs half-life determined for the 167-keV γ-ray activity in $^{189}$Pt was difficult to reconcile with the 0.5-μs half-life observed in the $^{189m}$Au decay study[7]. However, when the $^{189}$Pt coincidence tapes were resorted with a time gate set on a 200-400 ns delayed portion of the TAC spectrum and an energy gate on the 167-keV peak, several γ-rays including a moderately



strong 320-keV line were found to be in delayed coincidence with the 167-keV γ-ray. This result is compatible with the observation in the radioactivity study of a 321-keV transition populating the 0.5-μs state. It is apparent from the combined results that the 167-keV γ-ray occurs in the decay of the 0.5-μs isomer, which in the (α,3n) reaction is fed predominantly in the de-excitation of the 143-μs isomer and relatively weakly by other de-excitation pathways. There seems to be no indication that the 143-μs isomer is populated in the $^{189m}$Au decay.

In view of these findings, a search in the 200-400 ns range was also made for γ-rays in delayed coincidence with the 117- and 91-keV γ-rays of $^{187}$Pt and $^{191}$Pt, but none were found. Consequently a lower limit of 1 μs could be placed on the half-lives of the levels de-excited by these transitions.

## III. THE ISOMERIC DECAY SCHEMES

### The nucleus $^{193}$Pt

The 4.3-d $13/2^+$ isomer in $^{193}$Pt is well established[3]. Here the $13/2^+$ state de-excites by a 135-keV M4 transition to a $5/2^-$ state at 14 keV. No additional isomeric states in $^{193}$Pt were observed in the present work. All the high-spin states which are strongly populated in the (α,3n) reaction de-excite by γ-ray cascades leading to the 4.3-d $13/2^+$ isomeric state.

### The nucleus $^{191}$Pt

In the delayed γ-ray spectra, the only radiations observed to decay with the 95-μs half-life were Pt K X-rays and 91.1-keV (strong) and 48.4-keV (weak) γ-rays. The 91-keV transition is known to be of E2 character from earlier work[3,4]. From the γ-ray intensities observed in the $^{190}$Os(α,3n)$^{191}$Pt singles spectra, the 91-keV transition intensity was determined to be slightly larger

than the sum of the intensities of all the γ-rays feeding the $13/2^+$ isomeric state. By assuming that the 48- and 91-keV transitions occur in cascade in the de-excitation of the 95-μs isomer, a total conversion coefficient of $(6.0\pm0.8)\times 10^2$ was derived for the 48-keV transition from intensity balance requirements, indicating probable M2 multipolarity for this transition.

Important complementary information about the $^{191}$Pt level structure was obtained in a detailed study[9] of the radioactive decay of 3.2-h $^{191}$Au ($J^\pi = 3/2^+$). This investigation located many low-spin $^{191}$Pt levels not detectably populated in the (α,3n) reaction. In addition, we found that the $13/2^+$ isomer is populated quite strongly by cascades of $\Delta J = +1$ and $\Delta J = +2$ transitions from levels directly fed in the β-decay. In earlier conversion electron studies of the $^{191}$Au decay, a 48.4-keV M2 transition in $^{191}$Pt has been firmly established from subshell intensity ratios[10]. All our measurements indicate that this is the transition de-exciting the 95-μs isomer.

The proposed isomeric decay scheme is shown in Fig. 2. The placement of the $5/2^-$ level at 10 keV is strongly supported by our $^{191}$Au decay data. $J^\pi = 9/2^-$ for the 101-keV level is established by the multipolarities of the transitions feeding and de-exciting the level. As noted earlier, the delayed coincidence measurements in-beam indicate that the half-life of the $9/2^-$ level is greater than 1 μs.

The nucleus $^{189}$Pt

In this nucleus, the only radiations observed to decay with the 143-μs half-life were Pt K X-rays and 167-keV γ-rays. The 167-keV transition is of known E2 character[3], and its intensity observed in the γ-ray singles measurements was slightly larger than the summed intensities of the γ-rays feeding the $13/2^+$ isomer. The ISOLDE studies[7] of the 4.6-min $^{189}$Au ($J^\pi = 11/2^-$) decay



have shown that the 167 keV transition occurs in the de-excitation of a 464-ns $^{189}$Pt isomer, with probable spin-parity of $9/2^-$. We propose a decay scheme for the 143-μs isomer in $^{189}$Pt which is similar to that for $^{191}$Pt (Fig. 2). In this case the suggested M2 transition has not been observed; in our measurements, a low energy M2 transition ($E_\gamma < 45$ keV) or one close in energy to the Pt K X-rays would almost certainly have escaped detection. The level at 6 keV is known from a study[11] of the decay of 28.3-min $^{189}$Au ($J^\pi = 3/2^+$), and the $5/2^-$ spin-parity assignment is proposed because the pattern of its population following the β-decay is very similar to that of the 10-keV level in $^{191}$Pt.

The $^{187}$Pt nucleus

Here, the only radiations observed to decay with the 311-μs half-life were Pt K X-rays and 117-keV γ-rays. By attributing all the delayed Pt K X-rays to internal conversion of the 117-keV transition, a K conversion coefficient of 18±4 was estimated, indicating M2 multipolarity for the 117-keV transition. The requirement of intensity balance between the γ-rays feeding the $13/2^+$ isomer and the 117 keV transition de-exciting it also strongly favors the M2 multipolarity assignment. We suggest that the 117-keV transition may be analogous to the $13/2^+ \rightarrow 9/2^-$ isomeric transitions in $^{189}$Pt and $^{191}$Pt, but in the case of $^{187}$Pt no decay scheme can be proposed because the low-lying level structure is poorly established.

## IV. DISCUSSION

The decay schemes illustrated in Fig. 2 suggest an explanation for the striking difference between the long half-lives of the $\nu i_{13/2}$ isomers in odd-A Pt nuclei with $A \geq 193$ and the submillisecond half-lives of the $13/2^+$ isomers in $^{191}$Pt, $^{189}$Pt and $^{187}$Pt. Our detailed studies have established[1,12] that the

$13/2^+$ levels are definitely the lowest-lying members of the $\nu i_{13/2}$ level families in $^{193}$Pt, $^{191}$Pt and $^{189}$Pt, and the $13/2^+$ level is probably lowest-lying in $^{187}$Pt also. Therefore the most likely cause of the differences in the $13/2^+$ half-lives is that a level of moderately high spin occurs below the $13/2^+$ in the $A \leq 191$ nuclei, but above it in the heavier nuclei. The results of the present study strongly suggest that this intermediate level in the $A \leq 191$ nuclei has $J^\pi = 9/2^-$.

The nature of the $9/2^-$ levels is of some interest. The reduced transition probabilities for the transitions de-exciting the $9/2^-$ levels in $^{189}$Pt and $^{191}$Pt are B(E2;167 keV) = 0.08 s.p.u. and B(E2;91 keV) < 0.15 s.p.u., so they are obviously not collective excitations built on lower-lying levels. The most revealing evidence regarding these $9/2^-$ levels is provided by the 4.6-min $^{189}$Au decay data. The 0.5 μs $9/2^-$ state in $^{189}$Pt is populated in the β-decay of the $^{189}$Au $11/2^-$ isomer with a log ft of 4.7, indicating an allowed unhindered transition[7]. Since the $\pi h_{11/2}$ character of the 4.6-min $11/2^-$ state in $^{189}$Au is firmly established,[13,14] the $^{189}$Pt $9/2^-$ state fed in its β-decay must be of $\nu h_{9/2}$ parentage. In the prolate limit ($\gamma = 0°$), this $9/2^-$ state would be designated 9/2[505]ν; however, our results for the $\nu i_{13/2}$ level family in $^{189}$Pt indicate[12] a triaxial nuclear shape ($\gamma \sim 26°$). Almost certainly the $9/2^-$ levels in $^{191}$Pt and $^{187}$Pt have a similar nature. It is not surprising to find this $9/2^-$ intrinsic state at low energies in the light Pt nuclei, since 9/2[505]ν is known to be the ground state configuration in $^{191}$Os, and the same state has been located[3] 30 keV above ground in $^{189}$Os. Presumably the $9/2^-$ state lies above the $13/2^+$ isomers in the $A \geq 193$ Pt nuclei. In $^{195}$Pt, a $9/2^-$ level approximately 300 keV above the $13/2^+$ isomer is fairly strongly populated directly in the β-decay[15] of 3.7-h $^{195m}$Ir ($J^\pi = 11/2^-$).



As we have noted in the preceding paper[8], the existence of low-lying $9/2^-$ intrinsic states in $^{189}$Pt and $^{191}$Pt appears to be closely related to the occurrence of $10^-$ isomers of $\nu i_{13/2}$, $\nu h_{9/2}$ character in the neighboring core nuclei $^{190}$Pt and $^{192}$Pt.

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## References

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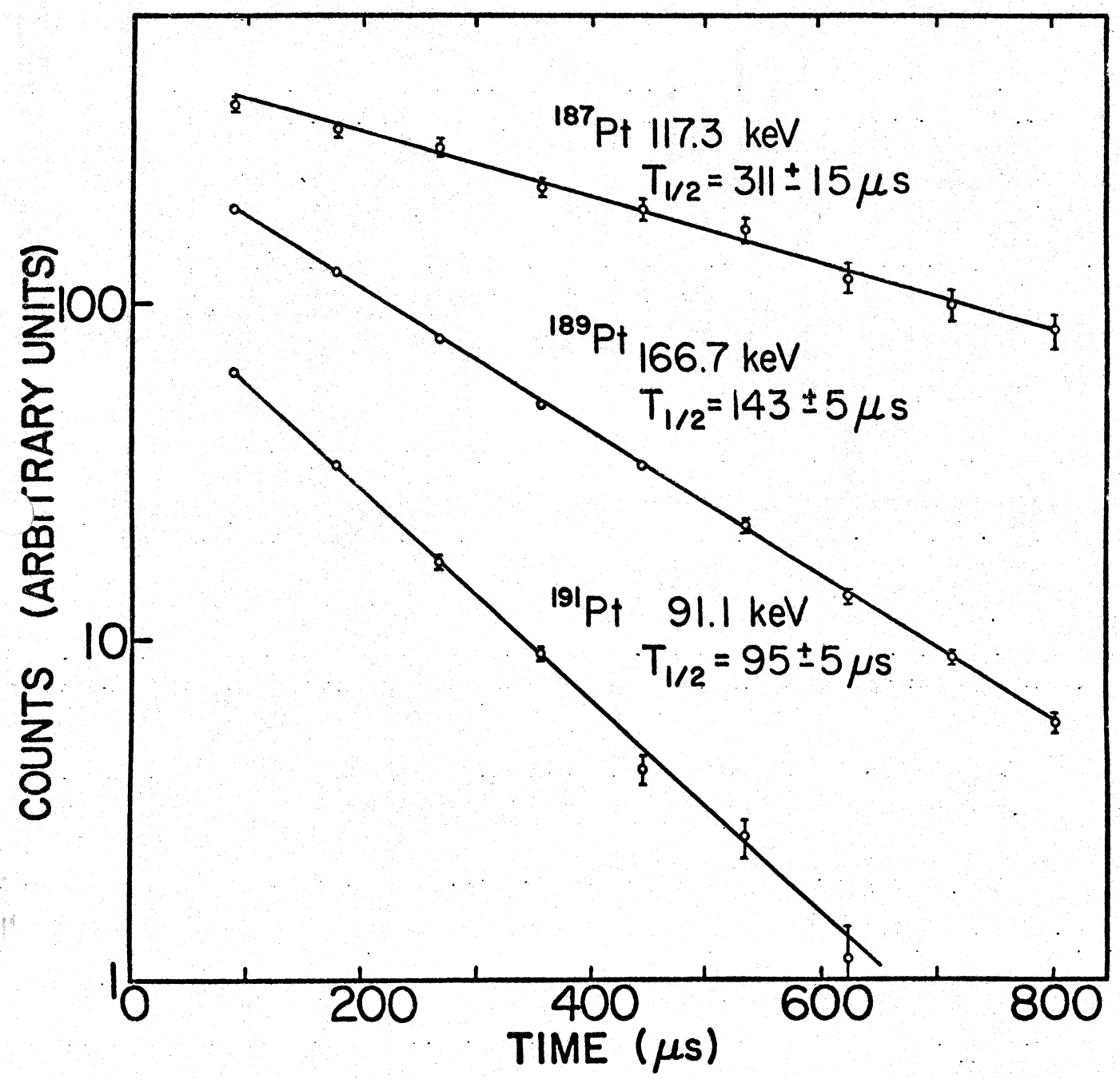
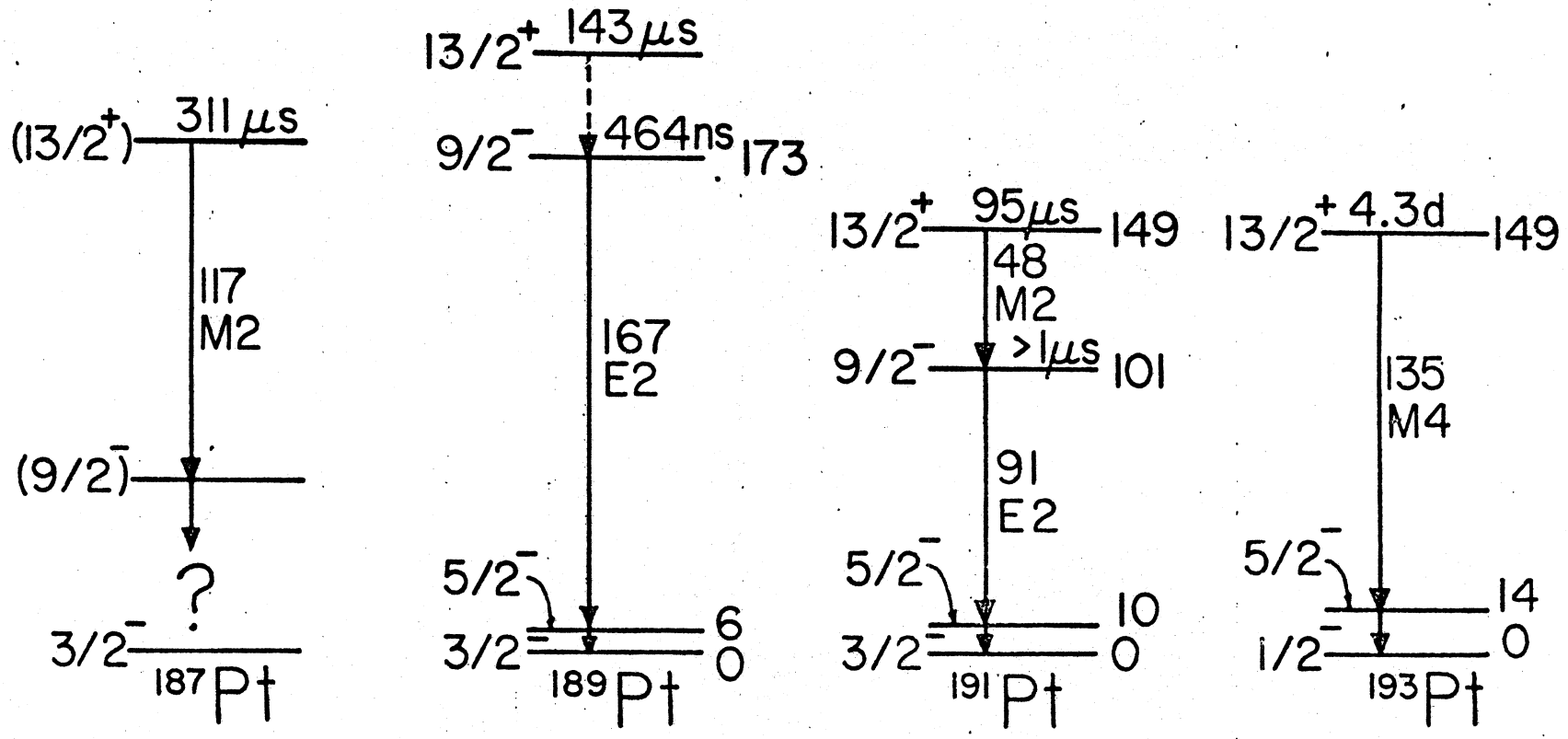
## Figure Captions

Fig. 1. The decay of the 117-, 167- and 91-keV γ-rays in $^{187}$Pt, $^{189}$Pt and $^{191}$Pt, respectively.

Fig. 2. The proposed isomeric decay schemes in odd-A Pt nuclei. The known $3/2^-$ level at 1.6 keV in $^{193}$Pt is not shown although it is populated in the 4.3-d decay.


$^{187}$Pt 117.3 keV
$T_{1/2}$ = 311 ± 15 μs
$^{189}$Pt 166.7 keV
$T_{1/2}$ = 143 ± 5 μs
$^{191}$Pt 91.1 keV
$T_{1/2}$ = 95 ± 5 μs
COUNTS (ARBITRARY UNITS)
100
10
1
0
200
400
600
800
TIME (μs)


(13/2+) 311 μs
117
M2
(9/2-)
?
3/2-
187Pt
13/2+ 143 μs
9/2- 464ns 173
167
E2
5/2-
6
3/2-
0
189Pt
13/2+ 95 μs 149
48
M2
9/2- >1 μs 101
91
E2
5/2-
10
3/2-
0
191Pt
13/2+ 4.3d 149
135
M4
5/2-
14
1/2-
0
193Pt