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HIGH-SPIN LEVEL SYSTEMATICS IN $^{177-182}W$: YRAST BAND ANOMALY IN ^{180}W*

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Abstract

High-spin levels in $^{177-182}W$ have been populated in $(\alpha,xn\gamma)$ reactions. Backbending-type behavior appears most prominently in ^{180}W. The role of $i_{13/2}$ neutrons and $h_{9/2}$ protons in the ^{180}W *yrast* behavior is examined. A strongly-coupled $K^{\pi} = 10^{+}$ band structure is identified in ^{182}W, the first seniority-two $i_{13/2}$ configuration to be characterized in a deformed nucleus.

The more neutron rich even-even tungsten isotopes are the only nuclei accessible by (*particle*,*xn*) reactions in the rare-earth region of deformation for which high-spin data on the *yrast* bands have yet to be reported [1]. The tungsten isotopes are of some interest in this regard, because they bridge a region between no backbending in the more neutron-rich hafnium isotopes [2], and a region of sharp *yrast* anomalies in the osmium isotopes [3,4]. The latter phenomena have recently been attributed by Neskakis *et al.* [4] to decoupling of $h_{9/2}$ protons. In contrast, backbending in the neutron-deficient lower-Z rare earth region is believed to result from decoupling of $i_{13/2}$ neutrons [5]. Thus, *yrast* band anomalies in the heavier tungsten isotopes might be expected to arise from influences similar to those at work in the osmium isotopes, but the tungsten isotopes have the added attraction of being in a region where the axially symmetric nuclear shape is expected to be quite stable.

In this letter, we summarize results of $(\alpha, xn\gamma)$ experiments carried out to populate levels in tungsten isotopes 177-182. Self-supporting foils of ^{177}Hf and ^{180}Hf were bombarded with beams of 26-50 MeV α-particles from the Michigan State University Cyclotron. Prompt and delayed γ-γ coincidence data, γ-ray excitation functions and angular distributions, and γ-time data relative to variable beam burst frequencies were obtained for each isotope studied. Details of the work on the odd-A isotopes 179 and 181 have been published previously [6-8], and are discussed here only as they pertain to the *yrast* behavior in the neighboring even-even isotopes.

The *yrast* band data for $^{177-182}$W are summarized in Fig. 1. A conventional $2\mathcal{J}/\hbar^2$ vs. $(\hbar\omega)^2$ plot of the even-A data is shown in Fig. 2. The

salient aspect of the data is the ^{180}W anomaly. The behavior of the *yrast* band very nearly qualifies ^{180}W for the family of "backbending" nuclei, and is at least as striking as the ^{170}Yb case which has recently received so much theoretical attention [9-13]. Furthermore, the effect is unique to ^{180}W among all the W isotopes with $98 \leq N \leq 108$, though some evidence for the behavior persists in ^{178}W. No such backbending behavior is seen in the corresponding Hf or Yb isotones, with the important exception of ^{170}Yb. An additional feature of interest in this context is our characterization (from γ-ray crossover/cascade ratios) of the 1.4-μsec, $K^{\pi} = 10^{+}$ isomer [14] in ^{182}W as a triplet coupling of the $9/2^{+}[624]$ and $11/2^{+}[615]$ neutrons. This provides the first experimental data on the location and behavior of a seniority-two, $i_{13/2}$ intrinsic configuration in the rare-earth deformed region.

Understanding the *yrast* behavior in ^{180}W within the framework of conventional explanations of backbending thus becomes an intriguing problem. The recent experiments at Jülich would lead one to expect that the backbending-type behavior in ^{180}W may simply be an extension into the W isotopes of the $h_{9/2}$ proton-induced backbending proposed in the Os isotopes [4]. However, the data for the neighboring odd-A W isotopes, 177, 179, and 181, show a remarkable correlation between the degree of decoupling in the $i_{13/2}$ bands in those nuclei, and the behavior of the *yrast* band in their even-A neighbors. Specifically, the rotation-particle decoupling quantity $[\langle \vec{R}^2 \rangle - \langle \vec{R}^2_{dec} \rangle]$ defined in ref. [15] shows that the $i_{13/2}$ particle is substantially more decoupled from the core rotation in ^{179}W than in either ^{177}W or ^{181}W. Plots of the relevant data are shown in Fig. 3. Note that ^{170}Yb is the single exception to the general rule that backbending in even-A nuclei is reflected by the decoupling tendency of the $i_{13/2}$ band in the (A-1) odd-mass neighbor [15]. It is significant that the rule holds also in the tungsten (not to mention osmium) isotopes. The high degree of particle-core decoupling displayed in the $i_{13/2}$ rotational band in ^{179}W is consistent with the ^{180}W anomalous g.r.b. structure. The more normal behavior of the ground bands in ^{178}W and ^{182}W should then be reflected in less decoupled $i_{13/2}$ structures in ^{177}W and ^{181}W compared to ^{179}W, and this is indeed found to be the case.≠

Thus, there is evidence for the involvement of $i_{13/2}$ neutrons in the ^{180}W *yrast* band anomaly, but it is not immediately clear what features in the $i_{13/2}$ single-particle spectrum would give rise to the special behavior in ^{180}W. One assumes there are no large, unexpected changes in quadrupole or hexadecapole deformation as one moves through the series $^{177-182}W$, and in general the spectroscopic data seem to support that assumption [16]. However, a systematic and relatively rapid increase in hexadecapole deformation is predicted [17] to occur between ^{176}W and ^{182}W, and it is expected that this will enhance the low-Ω components in the wave-functions of the low-energy $i_{13/2}$ states [16]. This feature is probably responsible for the backbending tendency in ^{178}W and ^{180}W, but the effect is quickly quenched by the emergence of the Fermi surface into the large gap in the single-particle spectrum expected [17] at N = 108. Indeed, it is evident that the Fermi surface in ^{181}W has moved substantially above the $7/2^+[633]$ orbit [7], quite in contrast to the situation in ^{179}W. Faessler [11] and others [9,10]

≠One expects the (A-1) odd-N nucleus should better predict the behavior of the even-A neighbor than should the (A+1) isotope because the Fermi surface in general moves less when an odd nucleon is paired than when a new odd nucleon is inserted into an already paired system.

have pointed out the sensitivity of the backbending phenomenon to the location of the Fermi surface in connection with similar behavior in $^{168-172}Yb$.

The appearance at 2231 keV of the $|9/2^+[624]; 11/2^+[615]>$ isomer and its strongly-coupled band in ^{182}W suggests that other seniority-two $i_{13/2}$ configurations of corresponding spin must lie still higher in the spectrum. Thus, in ^{182}W backbending in the usual spin range (14-18$\hbar$) cannot occur from intersection of the ground band with a decoupled $i_{13/2}$ 2-quasiparticle structure. However, the isomeric $i_{13/2}$ band, which apparently forms the *yrast* sequence above spin 16, should itself become decoupled at appreciably higher spin.

As for the possible involvement of $h_{9/2}$ protons, if indeed the intrusion of the $1/2^-[541]$ orbital produces the backbending-type behavior in ^{180}W, then one would expect an even more pronounced effect in ^{178}W, since experimental data [18] indicate the $1/2^-[541]$ orbit is several hundred kilovolts nearer the ground state in both ^{177}Ta and ^{179}Re than in ^{179}Ta and ^{181}Re. Nevertheless, the data of the Jülich group [4] provide compelling evidence for the role of $h_{9/2}$ protons in the backbending in ^{182}Os, an isotone of ^{180}W. This suggests that both $h_{9/2}$ protons and $i_{13/2}$ neutrons influence the *yrast* behavior in the W-Os region.

The question of the role of decoupled $h_{9/2}$ protons in the ^{180}W *yrast* band behavior may be resolved in a rather straightforward experiment. The $^{180}Hf(\alpha,5n\gamma)^{179}W$ reaction should easily allow one to populate the $i_{13/2}$ band to spins substantially greater than the 29/2 seen in $(\alpha,3n\gamma)$ experiments of Lindblad *et al.* [6]. If the backbending-type behavior in ^{180}W does arise from decoupling of an $h_{9/2}$ proton pair, the $i_{13/2}$ even-parity structure in ^{179}W should exhibit similar behavior near $(14 + \frac{13}{2})\hbar$. Should the $i_{13/2}$ neutrons ultimately be found to be responsible for *none* of the known *yrast* band irregularities in well-deformed nuclei with $N \gtrsim 100$, that surprising result would still be qualitatively consistent with the original proposal of Stephens and Simon [5] that backbending should occur only when the Fermi surface lies near low-Ω, high-j orbitals. Such a conclusion would then argue strongly that one largely understands the phenomenon of backbending throughout the rare earth region of a deformation.

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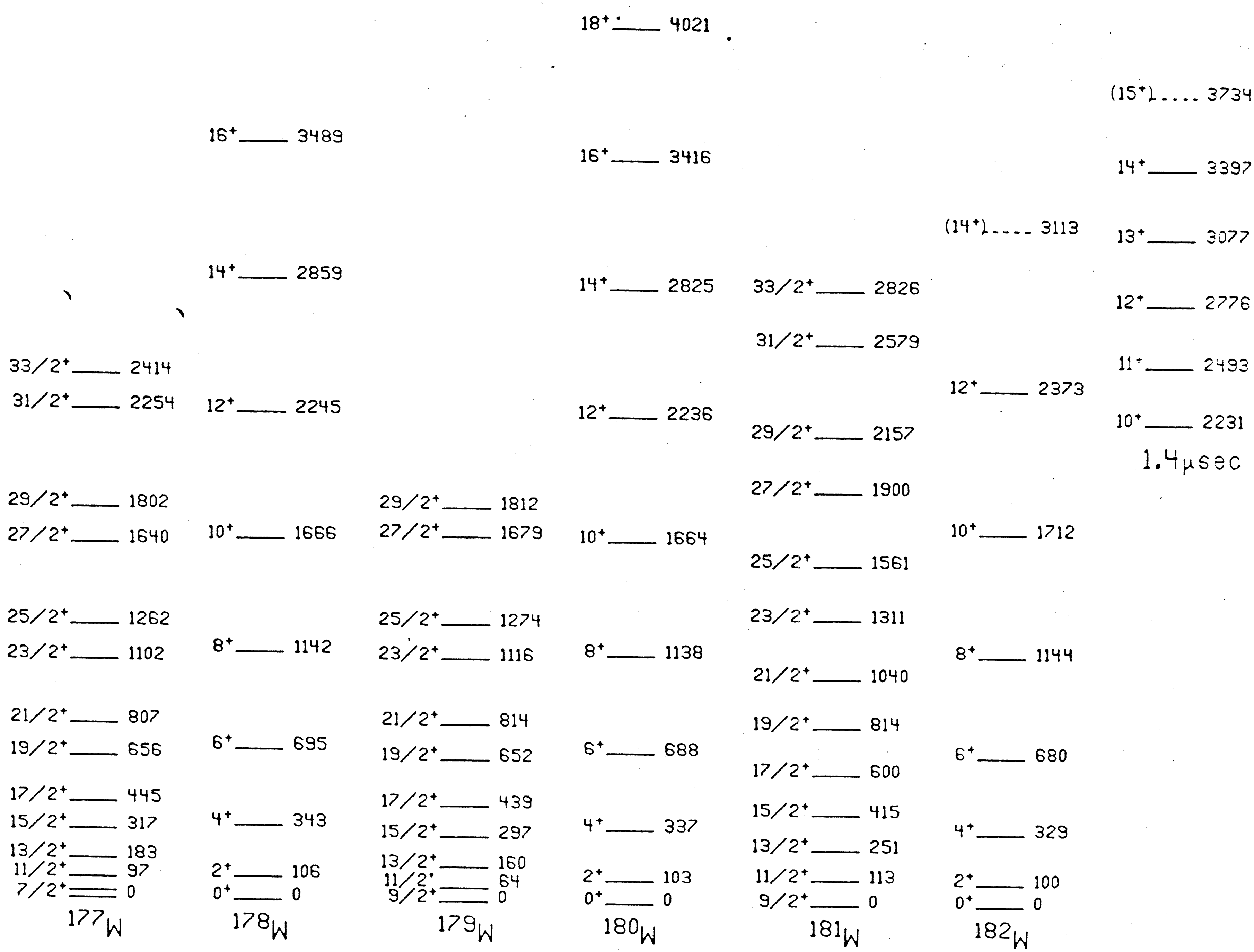
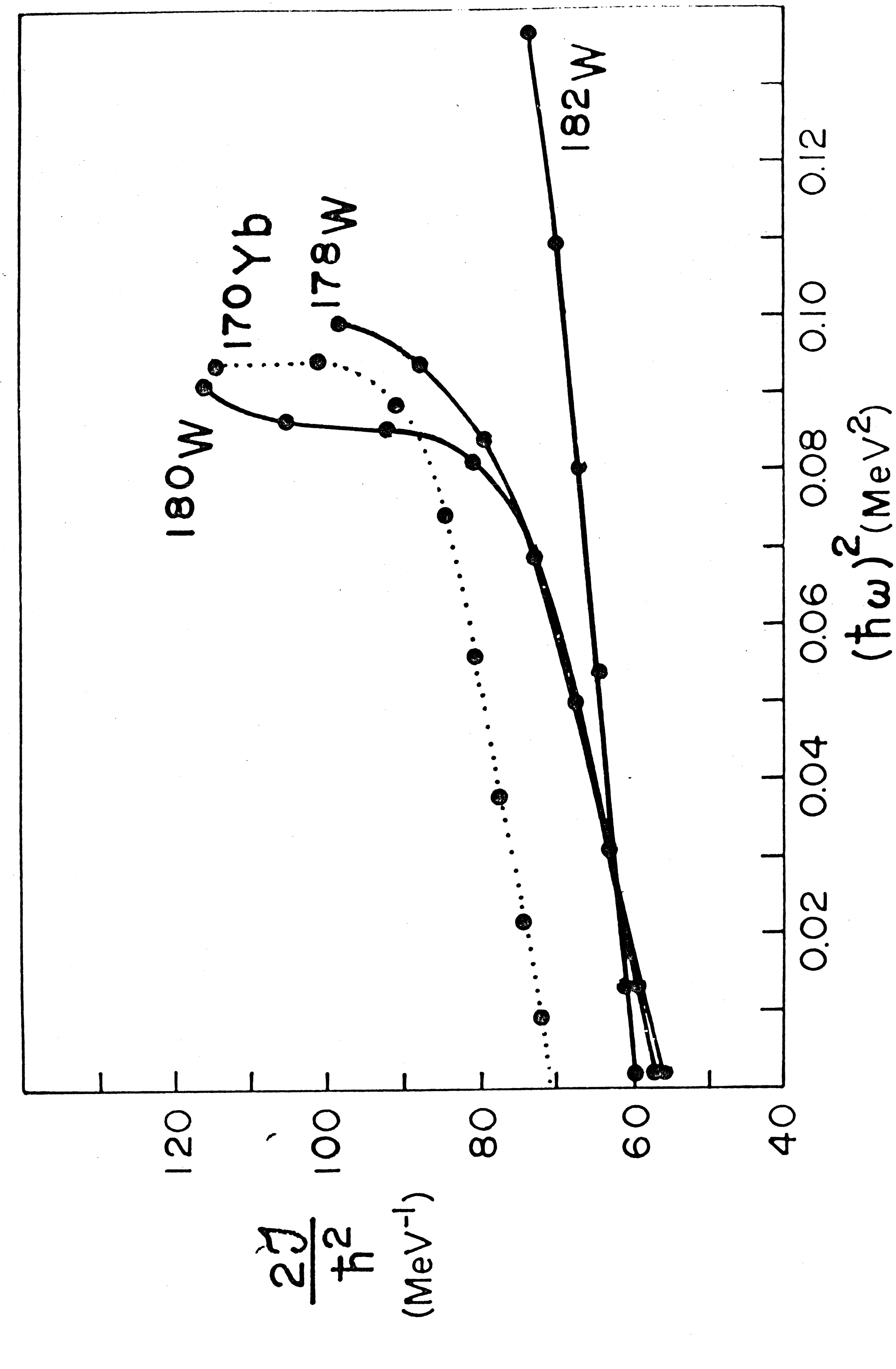
Figure Captions

1. The *Yrast* Band Structures in $^{177-182}W$. In 177 and 179, the even parity band becomes the *yrast* sequence at spin 9/2 and 15/2, respectively.
2. Backbending style plot of the *yrast* sequence in $^{178-182}W$. The ^{170}Yb data of ref. [9] are shown for comparison.
3. Rotation-particle decoupling for $i_{13/2}$ bands in odd-A tungsten isotopes. Several other cases are shown for comparison. The quantity plotted, $[\langle \vec{R}^2 \rangle - \langle \vec{R}^2_{dec} \rangle]$ is defined in ref. [15] and approaches zero in the decoupled ($\vec{I} = \vec{R} + \vec{j}$) limit.



(15⁺)....3734
14⁺ 3397
13⁺ 3077
12⁺ 2776
11⁺ 2493
10⁺ 2231
1.4μsec
(14⁺)....3113
12⁺ 2373
10⁺ 1712
8⁺ 1144
6⁺ 680
4⁺ 329
2⁺ 100
0⁺ 0
182W
33/2⁺ 2826
31/2⁺ 2579
29/2⁺ 2157
27/2⁺ 1900
25/2⁺ 1561
23/2⁺ 1311
21/2⁺ 1040
19/2⁺ 814
17/2⁺ 600
15/2⁺ 415
13/2⁺ 251
11/2⁺ 113
9/2⁺ 0
181W
18⁺ 4021
16⁺ 3416
14⁺ 2825
12⁺ 2236
10⁺ 1664
8⁺ 1138
6⁺ 688
4⁺ 337
2⁺ 103
0⁺ 0
180W
29/2⁺ 1812
27/2⁺ 1679
25/2⁺ 1274
23/2⁺ 1116
21/2⁺ 814
19/2⁺ 652
17/2⁺ 439
15/2⁺ 297
13/2⁺ 160
11/2⁺ 64
9/2⁺ 0
179W
16⁺ 3489
14⁺ 2859
12⁺ 2245
10⁺ 1666
8⁺ 1142
6⁺ 695
4⁺ 343
2⁺ 106
0⁺ 0
178W
33/2⁺ 2414
31/2⁺ 2254
29/2⁺ 1802
27/2⁺ 1640
25/2⁺ 1262
23/2⁺ 1102
21/2⁺ 807
19/2⁺ 656
17/2⁺ 445
15/2⁺ 317
13/2⁺ 183
11/2⁺ 97
7/2⁺ 0
177W

Figure 1



180W
170Yb
178W
182W
0.02
0.04
0.06
0.08
0.10
0.12
$(\hbar\omega)^2$ (MeV^2)
40
60
80
100
120
$\frac{2\mathcal{J}}{\hbar^2}$
(MeV^{-1})

Figure 2

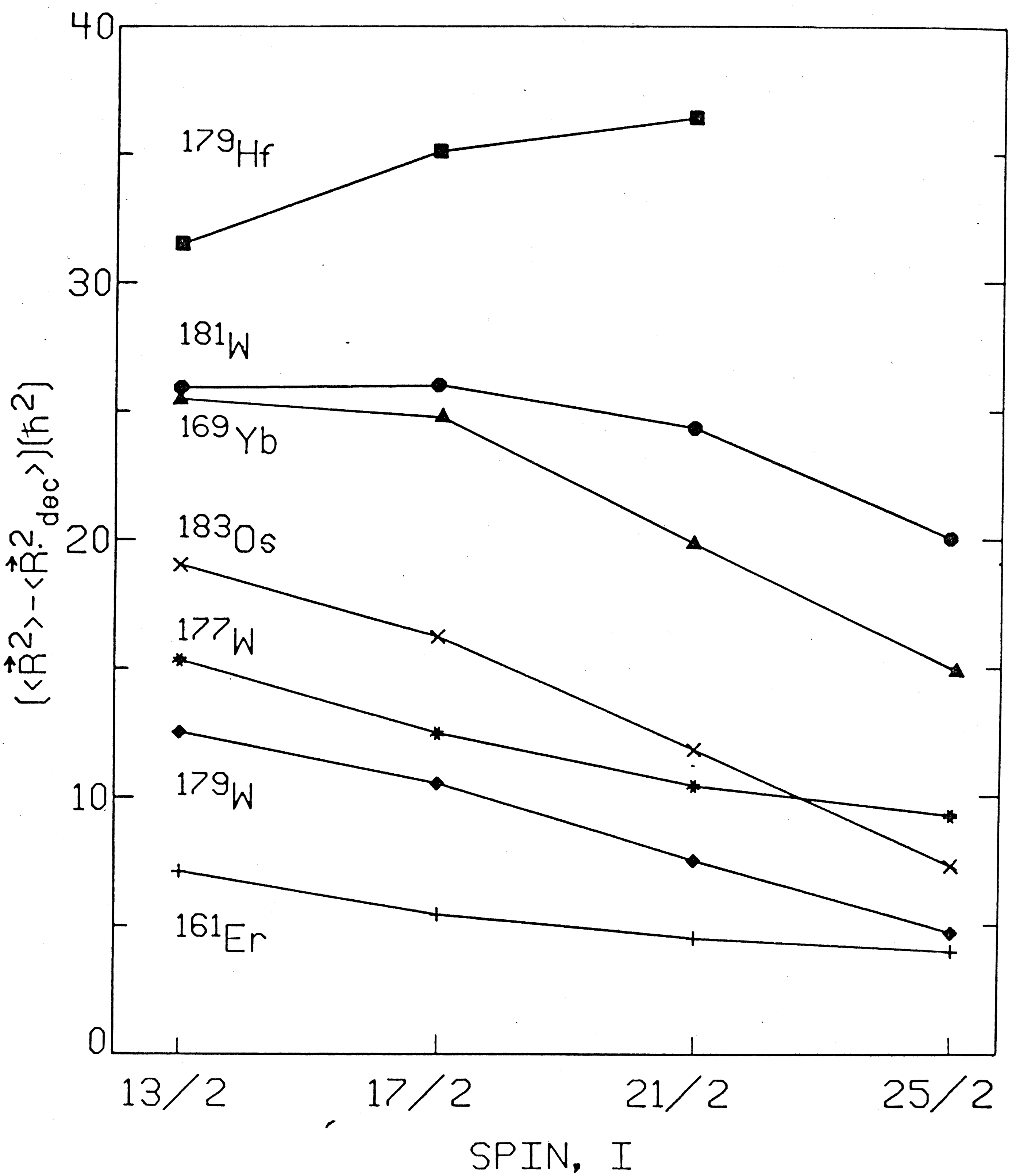

40
30
20
10
0
179Hf
181W
169Yb
183Os
177W
179W
161Er
(<R²>-<R²dec>)(ħ²)
13/2
17/2
21/2
25/2
SPIN, I

Figure 3