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# HIGH SPIN STATES AND BACKBENDING IN THE LIGHT TUNGSTEN ISOTOPES

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Abstract: High spin states in $^{172}W$, $^{174}W$, $^{175}W$ and $^{176}W$ have been studied with ($^{16}O$,xn) reactions. The ground state bands in $^{174}W$ and $^{176}W$ backbend in contrast to the more regular gsb in the N = 98 nucleus $^{172}W$. This behaviour and the anomalies in the odd nucleus $^{175}W$ are discussed in terms of the influence of neutrons on backbending.

Investigations of the high spin rotational band structure of deformed nuclei have revealed many instances of the anomalous behaviour known as backbending [Johnson and Szymanski 1973, Sorensen 1973]. The observation of backbending is intimately associated with the Heavy Ion, xn decay mechanism which proceeds through the yrast states. These are

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formed in the backbending region by a band with a relatively high moment of inertia which crosses the ground state band (gsb). This interpretation has recently been dramatically illustrated by the results of multiple Coulomb excitation through the backbending region [Lee et al. 1976]. The nature of the backbending and, essentially, the nature of the higher band was originally interpreted in terms of either a breakdown of pairing at high spin due to the Coriolis anti-pairing effect [CAP] [Mottelson and Valatin 1960, Krumlinde and Szymanski 1971], or a change in nuclear shape [Thieberger 1973], or the rotation alignment [RAL] of a single pair of high-j nucleons [Stephens and Simon 1971, Stephens 1975]. This last model has enjoyed considerable success, particularly in identifying the relationship between backbending in neighbouring odd and even nuclei. The anomalies (or their absence) in the high spin states of the rotational bands in the odd nucleus indicate the extent to which the intrinsic orbitals are responsible for the backbending [Grosse et al. 1973]. Thus, the $h_{11/2}$ protons appear to be involved in the Ba-Ce region [Ward et al. 1975], while the $i_{13/2}$ neutrons contribute in the heavier rare-earth region [Grosse et al. 1973, 1974; Riedinger et al. 1974, Rezanka et al. 1975], together with the $h_{9/2}$ protons [Foin and Barnéoud 1974; Foin, Andre and Barnéoud 1975]. Recently it was shown that $h_{9/2}$ protons are also the cause in the Os region [Neskakis et al 1976], although $i_{13/2}$ neutrons may still play a part in the Os isotopes, and in the heavier W nuclei [Bernthal et al 1974].

The role of neutrons in the W nuclei, as seen in terms of the odd and even -A relationship, was part of the scope of the present study. In addition, the systematics through the N = 98 region were studied because of the interest in the behaviour of the corresponding Yb isotones. Specifically, $^{168}$Yb (N = 98) does not backbend whereas its neighbours $^{166}$Yb, and particularly the N = 100 nucleus $^{170}$Yb, do backbend [Hartley et al 1973]. This dependence on neutron number is difficult to explain in terms of the RAL model [Stephens et al. 1974] and has led to the suggestion that the CAP effects are more significant in the N = 98 nucleus [Faessler et al. 1974, Goodman and Vary 1975]. Consequently the study of other nuclei through this region is important.

Backbending in the N = 96 nucleus $^{170}$W is known [Sayer et al 1975] and we present here results for $^{172}$W, $^{174}$W and $^{176}$W, and for the odd nucleus $^{175}$W. Although a significant proportion of the feeding intensity in the even nuclei studied here was found to populate sidebands, we have no evidence for the direct influence of these bands (in terms of band-crossing) in the backbending region, and for this report we will concentrate on the gsb transitions.

Oxygen beams with energies between 74 and 91 MeV from the ANU 14UD accelerator have been used with isotopically enriched, self supporting ($\sim$5 mgm/cm$^2$) dysprosium targets, to populate high spin states in the tungsten nuclei via the reactions $^{160,161,162,163,164}$Dy($^{16}$O,4n)$^{172,173,174,175,176}$W. Coincidence and lifetime information has been obtained for the de-excitation $\gamma$-rays from three parameter $\gamma$-$\gamma$-time and n-$\gamma$-time measurements (recorded event-by-event) with large volume Ge(Li) $\gamma$-ray detectors. A liquid scintillator with pulse shape discrimination was used for neutron detection. A 3.3 cm$^3$ high resolution Ge(Li) detector was also used to study the low energy transitions, particularly in $^{175}$W, and to establish coincidence and timing relationships. Singles $\gamma$-ray excitation functions and seven point angular distributions have been measured. For $^{175}$W, where many of the transitions were unresolved in singles, further coincidence measurements with the Ge(Li) detectors at 0° and 90° were used to provide correlation information to aid in assigning multipolarities, in addition to the singles distribution results.

The partial level schemes of the even isotopes are shown in figure 1. The lower spin states in $^{172,174,176}$W had been previously observed in singles measurements [Stephens Lark and Diamond 1965]. The deduced scheme for $^{175}$W is given in figure 2, while figure 3 shows a plot relating the apparent moment of inertia to the square of the rotational frequency for the gsb's of $^{172}$W and $^{174}$W, and for two of the intrinsic bands observed in $^{175}$W.

$^{172}$W: The gsb has been extended to spin $20^+$. There is no backbending although the apparent moment of inertia is seen to level off and approach the $^{174}$W value at high spin.

$^{174}$W: The gsb has been extended to spin $20^+$ (and possibly $22^+$) and backbends above spin 16.

$^{175}$W: Rotational bands are observed based on the $1/2^-[521]$, $5/2^-[512]$ and the $7/2^+[633]$ intrinsic states expected on comparison with the isotones $^{173}$Hf [Hultberg et al 1973] and $^{171}$Yb [Lindblad et al 1972]. These assignments are supported by the present lifetime measurements and deduced multipolarities, and are consistent with Coriolis coupling calculations based on the Nilsson model. The $1/2^-[521]$ band has been observed up to a spin of $37/2^-$, with backbending above spin $29/2^-$. The $7/2^+[633]$ band is identified, without backbending, to spin $41/2^+$. The $5/2^-[512]$ band is weakly populated and has only been assigned up to a spin of $25/2^-$.

$^{176}$W: The gsb is identified to spin $18^+$ where backbending occurs.

The behaviour of the backbending in the even W isotopes, as illustrated in figure 3 parallels that observed in the Yb nuclei [Hartley et al 1973]. Hartley et al proposed that the dependence on neutron number was due to the spacing of the Nilsson orbitals at the N = 98 Fermi surface. This spacing, with its consequent reduction in pairing correlations, was originally suggested as the explanation for the higher moments of inertia, evident in the low spin states of the W and Hf N = 98 nuclei [Stephens, Lark and Diamond 1964]. The RAL model has had difficulty in explaining the reappearance of backbending in the Yb nuclei as the neutron number is increased beyond N = 98. This is because the model depends on strong Coriolis effects which require the Fermi level to be close to the low $\Omega$ orbitals of the high j states. Therefore, if neutrons are responsible for the backbending, and $^{168}$Yb does not backbend, then neither should $^{170}$Yb, contrary to experiment. Similarly, if $^{172}$W does not backbend, then neither should $^{174}$W again in contrast to the experimental results reported here. Further, the role of protons cannot be invoked to explain the backbending since the results for $^{175}$W show that $i_{13/2}$ neutrons are primarily responsible. This is evident in the regular behaviour of the $7/2^+[633]$ orbital, the lowest $i_{13/2}$ orbital, whose occupation is blocking the decoupling process. In contrast, when the odd neutron occupies another orbital, as in the $1/2^-[521]$ band, the backbending is not prevented and even takes place at a lower rotational frequency, as has been observed in other instances [Riedinger et al 1974].

The similar behaviour of the Yb and W isotones suggests a common cause which is not easily explained in the RAL model. However, in this context it is surprising that the N = 100 nucleus $^{172}$Hf, which lies between $^{170}$Yb and $^{174}$W does not backbend at least up to spin $18^+$

[Stephens et al 1965, Skaali et al 1975]. It would be of considerable interest to extend the $^{172}$Hf level scheme to higher spin, and to examine the odd-proton nuclei in this region to clarify the role of both protons and neutrons.

The realistic interpretation of backbending will probably include both CAP and RAL effects (in protons and neutrons) as is evident from the results of extensive microscopic calculations reported by Faessler et al [1976] and Goodman [1976]. Goodman concludes that CAP effects are dominant in $^{168}$Yb while RAL in the $i_{13/2}$ neutrons causes backbending in $^{170}$Yb. It would seem worthwhile to test these calculations on the tungsten nuclei which, as reported here, behave (experimentally) in a similar fashion.

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## FIGURE CAPTIONS

**Figure 1:** The ground state rotational bands of $^{172}W$, $^{174}W$ and $^{176}W$, as observed in the $(^{16}O,4n)$ reactions. For convenience, transition energies (which were measured to an accuracy of about 0.15 keV) are given to the nearest kilovolt.

**Figure 2:** Level scheme for transitions observed in the de-excitation of $^{175}W$ after the $(^{16}O,4n)$ reaction. Transitions for which no energy is quoted are less than 35 keV and were undetected. For convenience, transition energies (which were measured to an accuracy of .15 keV) are given to the nearest kilovolt.

Figure 3: The apparent moments of inertia $2\mathcal{J}/\hbar^2$ related to the square of the rotational frequency. The conventions adopted are those of Grosse et al. [1973] with $R \equiv I$ for the even nuclei and $R = I - j$, $j = 13/2$ for the $7/2^+[633]$ bard in $^{175}W$; $R = I - j$, $j = 5/2$ for the $1/2^-[521]$ band in $^{175}W$; together with the relations

$$2\mathcal{J}/\hbar^2 = (4R-2)/(E(R)-E(R-2)) \quad \text{and}$$

$$\hbar^2 w^2 = (E(R) - E(R-2))^2/4 \ .$$

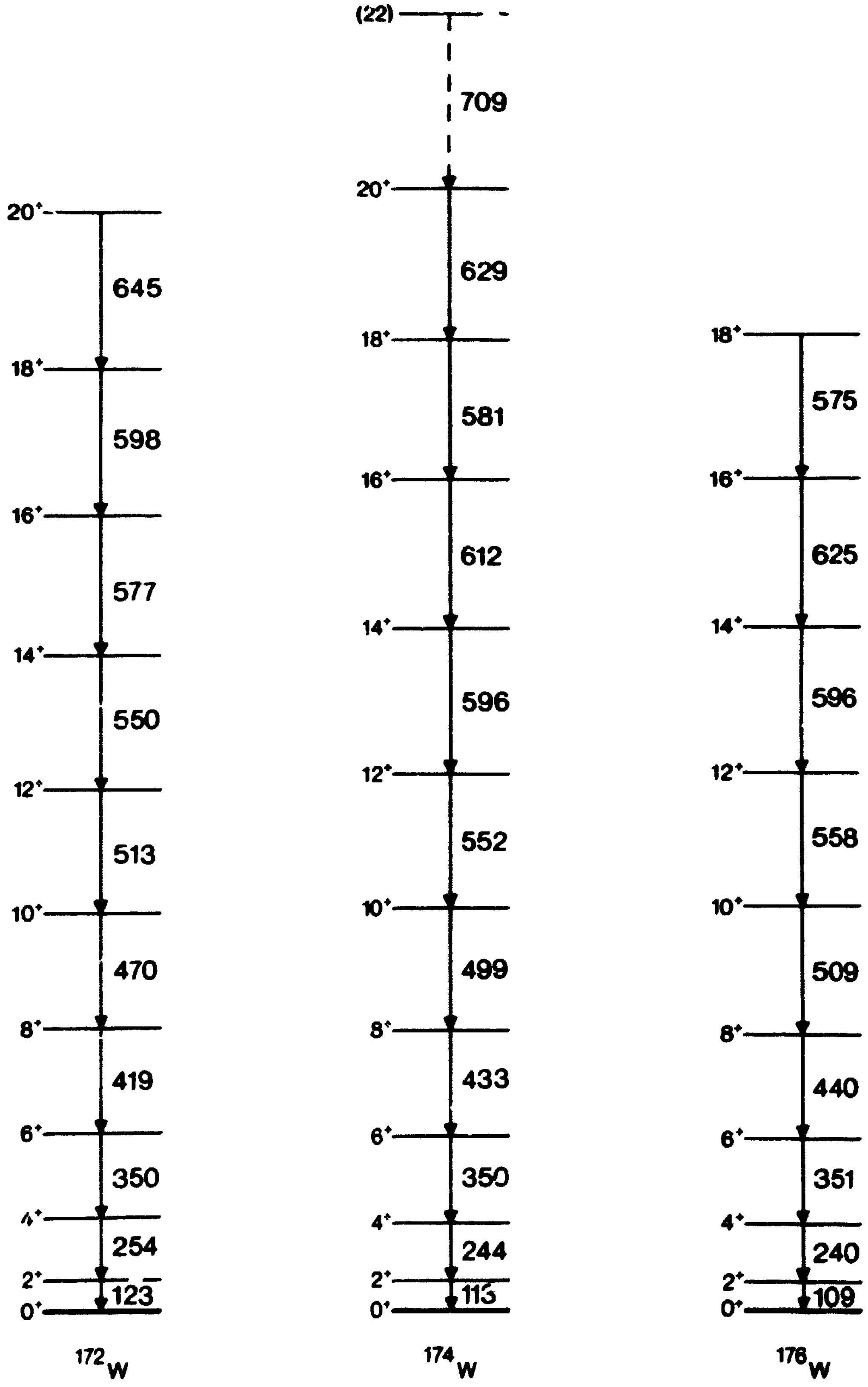

(22)
709
20⁺
629
18⁺
581
16⁺
612
14⁺
596
12⁺
552
10⁺
499
8⁺
433
6⁺
350
4⁺
244
2⁺
113
0⁺
174W
20⁺
645
18⁺
598
16⁺
577
14⁺
550
12⁺
513
10⁺
470
8⁺
419
6⁺
350
4⁺
254
2⁺
123
0⁺
172W
18⁺
575
16⁺
625
14⁺
596
12⁺
558
10⁺
509
8⁺
440
6⁺
351
4⁺
240
2⁺
109
0⁺
176W

Figure 1.

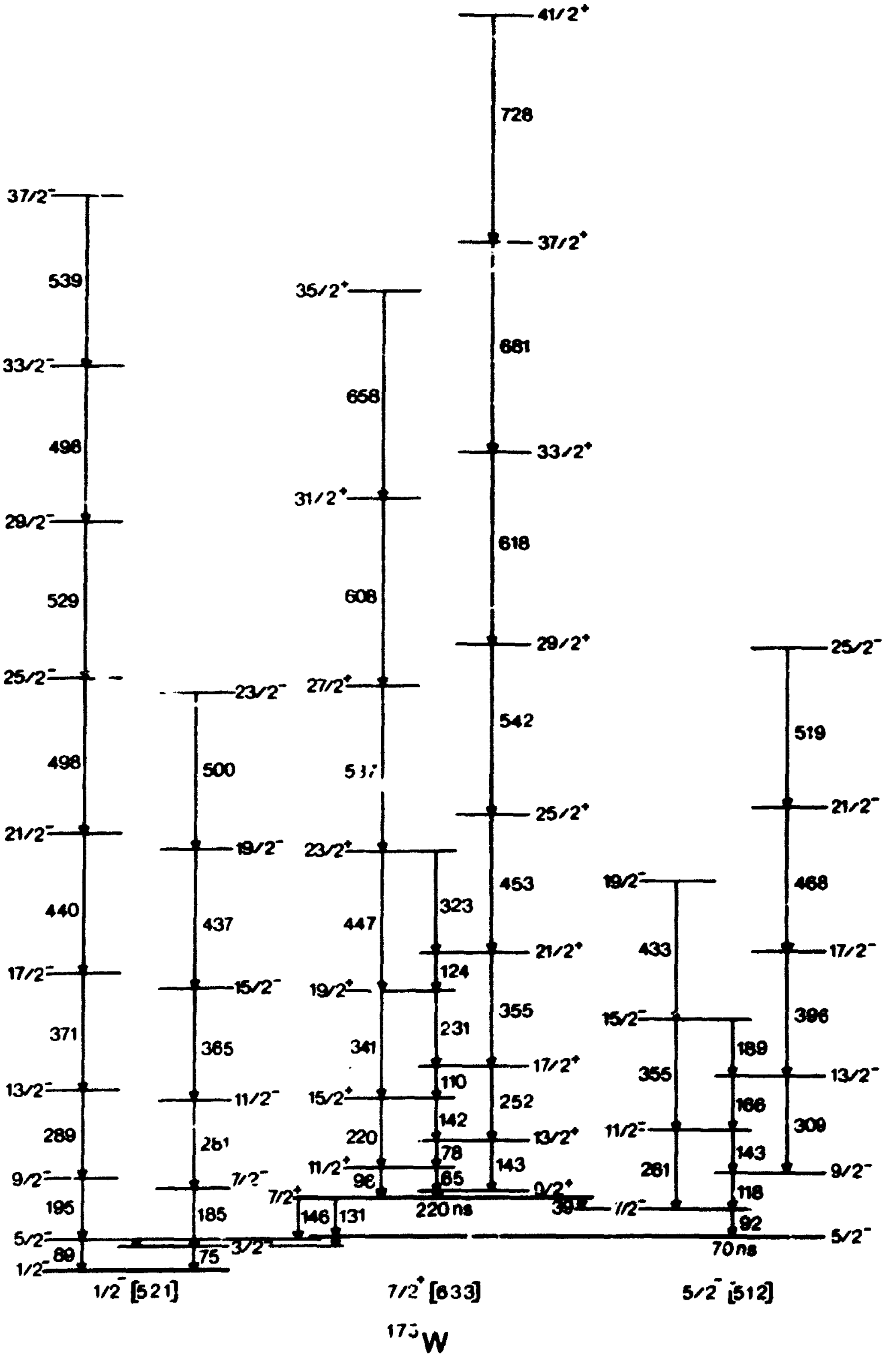
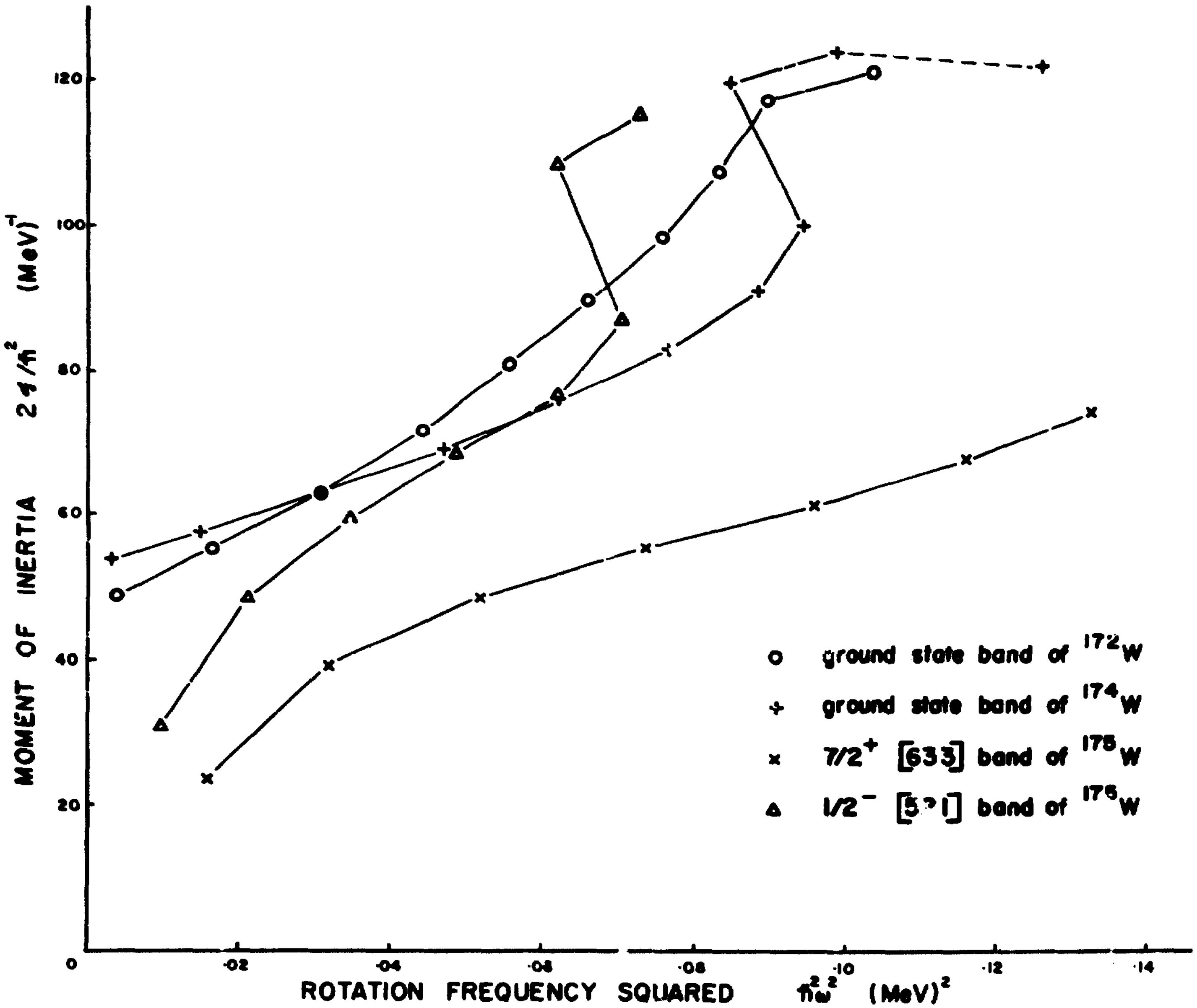

37/2⁻
539
33/2⁻
496
29/2⁻
529
25/2⁻
498
21/2⁻
440
17/2⁻
371
13/2⁻
289
9/2⁻
195
5/2⁻
89
1/2⁻
23/2⁻
500
19/2⁻
437
15/2⁻
365
11/2⁻
261
7/2⁻
185
3/2⁻
75
1/2⁻ [521]
35/2⁺
658
31/2⁺
608
27/2⁺
537
23/2⁺
447
19/2⁺
341
15/2⁺
220
11/2⁺
98
7/2⁺
146
131
220 ns
323
124
231
110
142
78
65
41/2⁺
728
37/2⁺
681
33/2⁺
618
29/2⁺
542
25/2⁺
453
21/2⁺
355
17/2⁺
252
13/2⁺
143
9/2⁺
39
7/2⁺ [633]
19/2⁻
433
15/2⁻
355
11/2⁻
261
7/2⁻
189
166
143
118
92
70 ns
25/2⁻
519
21/2⁻
468
17/2⁻
396
13/2⁻
309
9/2⁻
5/2⁻
5/2⁻ [512]
173W

Figure 2.



MOMENT OF INERTIA $2\mathcal{I}/\hbar^2$ (MeV)$^{-1}$
20
40
60
80
100
120
0
·02
·04
·06
·08
·10
·12
·14
ROTATION FREQUENCY SQUARED $\hbar^2\omega^2$ (MeV)$^2$
○ ground state band of $^{172}$W
+ ground state band of $^{174}$W
× 7/2$^+$ [633] band of $^{175}$W
△ 1/2$^-$ [521] band of $^{175}$W

Figure 3.