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CONTRASTING HIGH SPIN YRAST BANDS IN ^{172}Os AND ^{174}Os AND AN UNEXPECTED LOW FREQUENCY ANOMALY IN ^{172}Os.

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Abstract: The yrast bands of the neutron deficient isotopes ^{172}Os and ^{174}Os have been identified to spins of about 24 $\hbar$. The yrast band in ^{174}Os shows no bandcrossing anomalies, confirming the shell effect observed in other N=98 nuclei. In contrast, a strong backbend is observed at a frequency of about 0.26 MeV in ^{172}Os and is attributed to the s-band crossing. A weaker bandcrossing is also observed at a lower frequency, about 0.24 MeV, in ^{172}Os. This unexpected anomaly may be due to either a deformation effect, or to a change in the s-band structure.

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The backbending behaviour of the osmium nuclei is established over a large range of well deformed isotopes from ^{176}Os to ^{186}Os [1-3]. These have approximately constant quadrupole deformation ε_2, and varying hexadecapole deformation ε_4. We present here new results for the very neutron deficient nuclei ^{172}Os and ^{174}Os which extends the range into the region of reduced deformation, as predicted by Strutinsky - type calculations of the potential energy surface [4].

High spin states in ^{172}Os and ^{174}Os were formed using beams from the ANU 14UD Pelletron accelerator in the ^{148}Sm(^{28}Si,4n)^{172}Os and ^{150}Sm(^{28}Si,4n)^{174}Os reactions at 145 and 138 MeV respectively, the optimum energies chosen from excitation functions. New transitions were assigned from γ-γ coincidence measurements with a Compton-suppressed Ge(Li) detector, used in conjunction with two other Ge(Li) detectors. Doppler effects, which would lead to broadening of the short lifetime high spin transitions because of the large recoil velocities (about 1.4% v/c), were reduced by allowing the nuclei to recoil out of the relatively thin targets (1 mg/cm^2) and decay in flight. Fully Doppler shifted transitions were observed in the Compton suppressor placed at 0° while the other detectors were placed at 90° and 130° respectively, each detector subtending a relatively small solid angle. The backward angle detector provided an additional consistency check on the identification of Doppler shifted transitions.

Gamma-ray angular distributions were measured at six angles between 0° and 90° using the Compton suppressor, and in this case, 1.5 mg/cm^2 thick targets evaporated directly on to uranium backings. A significant reduction in background from low-multiplicity contaminants such as activity, and target Coulomb excitation, was obtained by demanding a coincidence between the Compton suppressor and one or more of the elements of a multiplicity filter comprising six, 5cm × 5cm, NaI detectors placed in a halo, symmetrically about the beam axis, upstream from the target. Correlation effects were checked by comparing the anisotropies obtained for the different coincidence folds (n), and were found to be small.

The yrast transitions assigned to ^{172}Os and ^{174}Os are given in table 1, with their relative intensities and angular distribution coefficients (for $n \geq 2$). Several sidebands, feeding into the yrast bands near spin 8, were observed in each nucleus. They will not be discussed here, but they were useful in establishing the ordering of some of the low spin yrast transitions. The assigned transitions agree with the limited earlier information on ^{172}Os and ^{174}Os which suggested transitions up to spin 6 in ^{172}Os and spin 10 in ^{174}Os, from singles measurements [5].

The quality of the coincidence data taken with the Compton suppressor is illustrated in figure 1 which compares γ-ray coincidence spectra in ^{172}Os and ^{174}Os. The regular behaviour of the ground state band (gsb) in ^{174}Os contrasts strongly with the irregular spacing observed at low spin in ^{172}Os. The ordering of the transitions is assigned from coincidence relationships, and singles and coincidence intensities. The highest spin transitions, supported by individual coincidence spectra, are also evident in the spectra obtained by summing several gsb gates, as shown in the inset spectra.

The behaviour of the yrast bands is shown in figure 2 in plots of the parameter I_x, the aligned angular momentum, against $\hbar\omega$, the rotational frequency, deduced from the transition energies using the prescription of Bengtsson and Frauendorf [6]. The yrast curve for ^{174}Os is smooth up to a high frequency, $\hbar\omega$ = 0.40 MeV, in contrast to the heavier isotopes in which anomalies are observed at frequencies ranging from 0.31 MeV in ^{176}Os to 0.26 MeV in ^{182}Os [1,3]. The absence of an anomaly in ^{174}Os can be attributed to the large yrast-yrare mixing predicted for N = 98 nuclei [6] and the reduced pairing in the gsb because of a local shell structure in the Nilsson neutron orbitals. The pairing is the main cause of the low moment of inertia in the gsb compared to the rigid body value and its reduction leads in turn to the more rapid rise in the gsb moment of inertia with increasing frequency, an increase in the Coriolis anti pairing effect (CAP). The neutron shell effect persists over a large range of proton number from Z=68 to Z=76, confirming the uniqueness of the deformed N=98 nuclei in the backbending systematics [7,8].

In contrast, detailed analysis shows that two anomalies are present in the yrast sequence of ^{172}Os. The prominent one at $\hbar\omega$ = 0.26 MeV is attributed to the crossing with the s-band, presumably the rotation aligned $(i_{13/2})^2$ neutron band, as is the case in the heavier isotopes [1,9] (excluding ^{174}Os). Support for this assignment comes from consideration of the observed frequency and aligned angular momentum. The equivalent anomaly in the isotone ^{170}W is observed at $\hbar\omega$ = 0.248 MeV [10] as recently analysed by Michel and Vervier [11]. Although the band crossing frequency predicted in the framework of the cranked shell model (CSM), reported by Michel and Vervier [11], is somewhat lower than that observed experimentally, this is a general trend in the comparison between the CSM theory and experiment, and the theory does predict similar frequencies for the N=96 isotones ^{170}W and ^{172}Os, as observed. The nett rotation aligned angular momentum i_R can be deduced from a fit of the s-band curve in the region above the anomaly, between spins 18 and 24, to the formula $I_x = i_R + \mathcal{J}_0\omega + \mathcal{J}_1\omega^3$ where $\mathcal{J}_0$ and $\mathcal{J}_1$ are the moment of inertia parameters, as suggested by Bengtsson [12]. This gives i_R = 8.9 $\hbar$ for ^{172}Os, in agreement with the values of 9.1 $\hbar$ for the isotone ^{170}W, and 9.0 $\hbar$ for the heavier isotope ^{178}Os.

However, the shape of the yrast curve is not consistent with that expected from a two-band mixing picture as used in ref. [11] and [1], because of the extra anomaly at low frequency. This is evident if one attempts to reconstruct the observed yrast sequence using extrapolations of the gsb from the low-spin region, and parameters for the s-band deduced from the high spin region, a procedure which was successful for the heavier isotopes [1]. Essentially this is because of the deviation from a smooth curve evident at low spin, beginning at the $8^+ \rightarrow 6^+$ transition. The deviation can also be seen in a plot of the energy difference between successive yrast transitions as a function of spin, given in the inset in figure 2. As suggested by Peker and Hamilton [13] a dip in this curve indicates a band crossing, such as that observed at spin 16. The dip near spin 8 is less pronounced, but clear.

The low spin anomaly requires explanation. One possibility is a jump in deformation at low frequency. ^{172}Os is expected to be soft to deformation since it will be close to γ-instability. This can be seen from the ratio of excitation energies $E^{4^+}/E^{2^+} = 2.66$, which can be compared to the value for "ideal" γ-instability of ≤ 2.5 given by Wilets and Jean [14]. This is also consistent with the shallow potential well calculated by Ragnarsson et al [4], and the relatively small difference between the depth of the prolate and oblate minima in that potential. The effective moment of inertia reached in the yrast band above the low frequency anomaly, (but below the second anomaly attributed to the s-band crossing), is close to that observed in the heavier (more deformed) isotopes $^{176-180}$Os at the same frequency. That would imply about a 15% increase in deformation compared to the ^{172}Os ground state. If this were the correct explanation a related effect would be expected in nuclei with similar deformation (potential well) parameters, those related to ^{172}Os by the addition or subtraction of an α-particle; ^{168}W and ^{176}Pt. The level scheme for ^{168}W is not known and only two states are known [15] in ^{176}Pt, a 2^+ state at 263 keV (comparable to the 2^+ energy in ^{172}Os) and a low lying excited (0^+) state at 433 keV.

Nevertheless, coexistence between deformed and "spherical" shapes is known in the very light Hg isotopes [16,17] where a crossing between the deformed (excited) bands and the less deformed gsb is observed at very low spins. In those cases the 0^+ bandhead of the deformed configuration is at a comparable excitation energy to the 0^+ state observed in ^{176}Pt. To pursue the analogy further, if a deformed band with the same moment of inertia as that observed in ^{184}Hg [16] is assumed to exist in ^{172}Os, based at about 433 keV as suggested by the ^{176}Pt scheme, it would result in a band crossing in ^{172}Os near spin 8. The anomaly in ^{172}Os is less dramatic and at higher spin than that observed in the Hg isotopes because the ground state configuration in ^{172}Os is more deformed.

An alternative explanation is that an effect related to that recently suggested by Garrett and Frauendorf [18] is being observed. They explain the change in moment of inertia at low frequencies in the heavier osmium isotopes, an effect related to CAP and evident in the large and changing $\mathcal{J}_1$ parameter required to describe the gsb's in these nuclei, as being due to a change in character of the s-band from one dominated at low frequencies by the high-Ω components of the $i_{13/2}$ neutron orbitals, to one with predominantly low-Ω components at high frequencies. This implies strong mixing with the gsb at low frequencies, and weaker mixing, and therefore a more pronounced anomaly at high frequencies. Whether such a change in character in the s-band would be abrupt enough to lead to a distinct separation between the two regions, as implied by the present yrast band data, is not clear at this stage. Calculations in the CSM framework might clarify this suggestion.

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Table 1: Yrast transitions in ^{172}Os and ^{174}Os. Distribution coefficients are for $n \geq 2$ fold coincidences with the multiplicity filter.

^{172}Os

E_γ (keV)	I_γ	transition $I_i \rightarrow I_f$	A_2/A_0	A_4/A_0
228.0	86 (2)	2→0	0.243(14)	-0.096(17)
378.7	100 (2)	4→2	0.267(14)	-0.083(16)
448.7	92 (3)	6→4	0.280(15)	-0.09 (2)
471.1	73 (2)	8→6	0.275(15)	-0.09 (2)
499.7	50 (2)	10→8	0.262(17)	-0.06 (2)
541.2	45 (3)	12→10	0.386(23)	-0.14 (3)
537.3	36 (3)	14→12	0.317(26)	-0.06 (3)
488.2	27 (2)	16→14	0.25 (8)	-0.01 (12)
587.5	17 (3)	18→16	0.22 (5)	-0.11 (6)
655.9	9 (2)	20→18	0.24 (9)	0.00 (11)
696	5 (1)	22→20		
726	1.6 (5)	24→22		

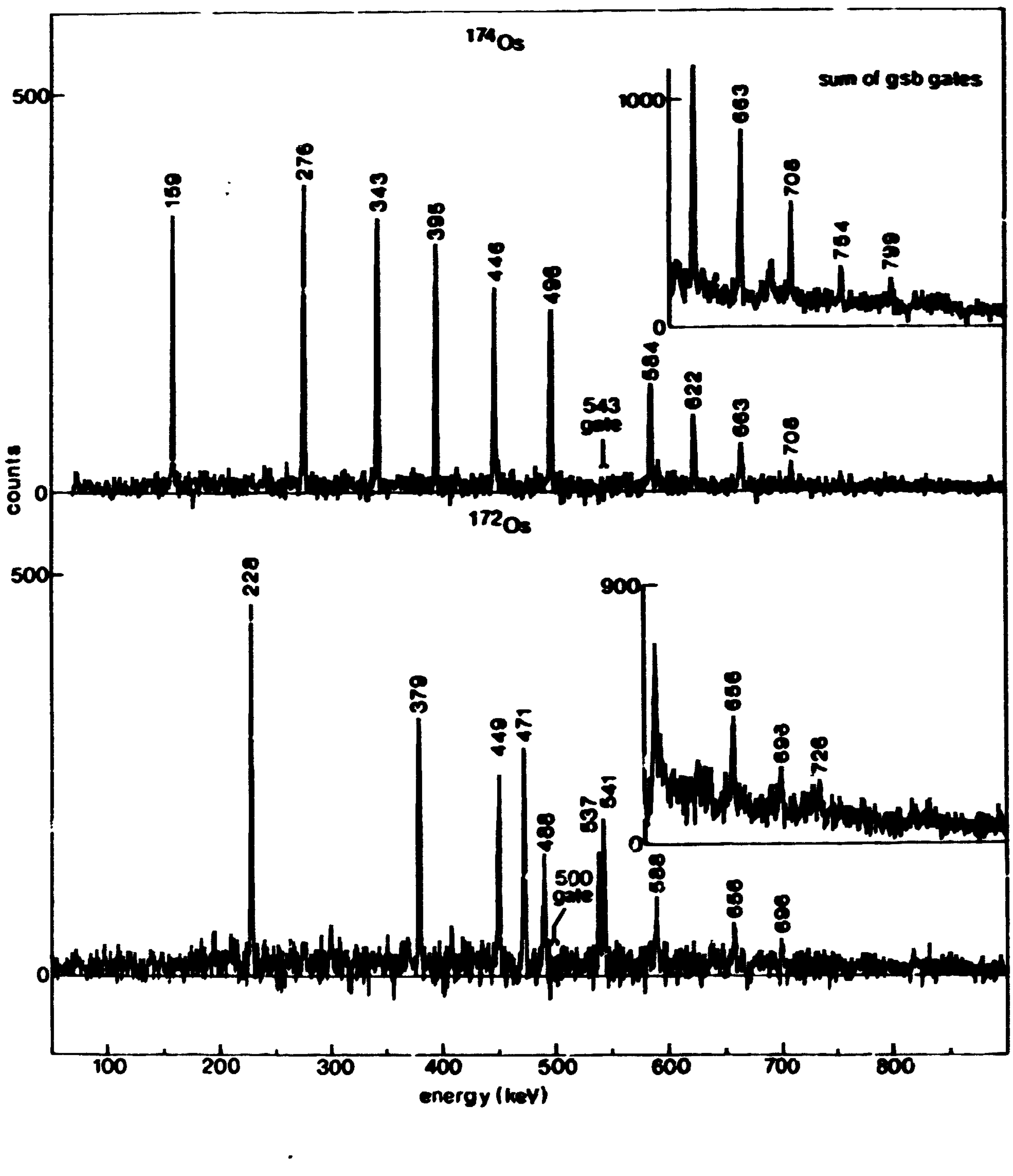
^{174}Os

E_γ (keV)	I_γ	transition $I_i \rightarrow I_f$	A_2/A_0	A_4/A_0
158.8	63 (2)	2→0		
276.3	98 (3)	4→2	0.32 (2)	-0.13 (2)
342.8	100 (3)	6→4	0.33 (2)	-0.13 (2)
394.5	85 (4)	8→6	0.31 (2)	-0.12 (2)
446.0	71 (4)	10→8	0.32 (2)	-0.13 (2)
496.4	53 (3)	12→10	0.33 (3)	-0.12 (3)
542.9	46 (2)	14→12	0.31 (2)	-0.13 (3)
584.0	40 (2)	16→14	0.29 (2)	-0.14 (3)
622.0	26 (1)	18→16	0.28 (4)	-0.09 ([illegible])
663.3	17 (1)	20→18	0.33 (4)	-0.13 (5)
708.1	15 (1)	22→20	0.30 (7)	-0.03 (8)
754.0	6 (1)	24→22		
799.1	4 (1)	26→24		

FIGURE CAPTIONS

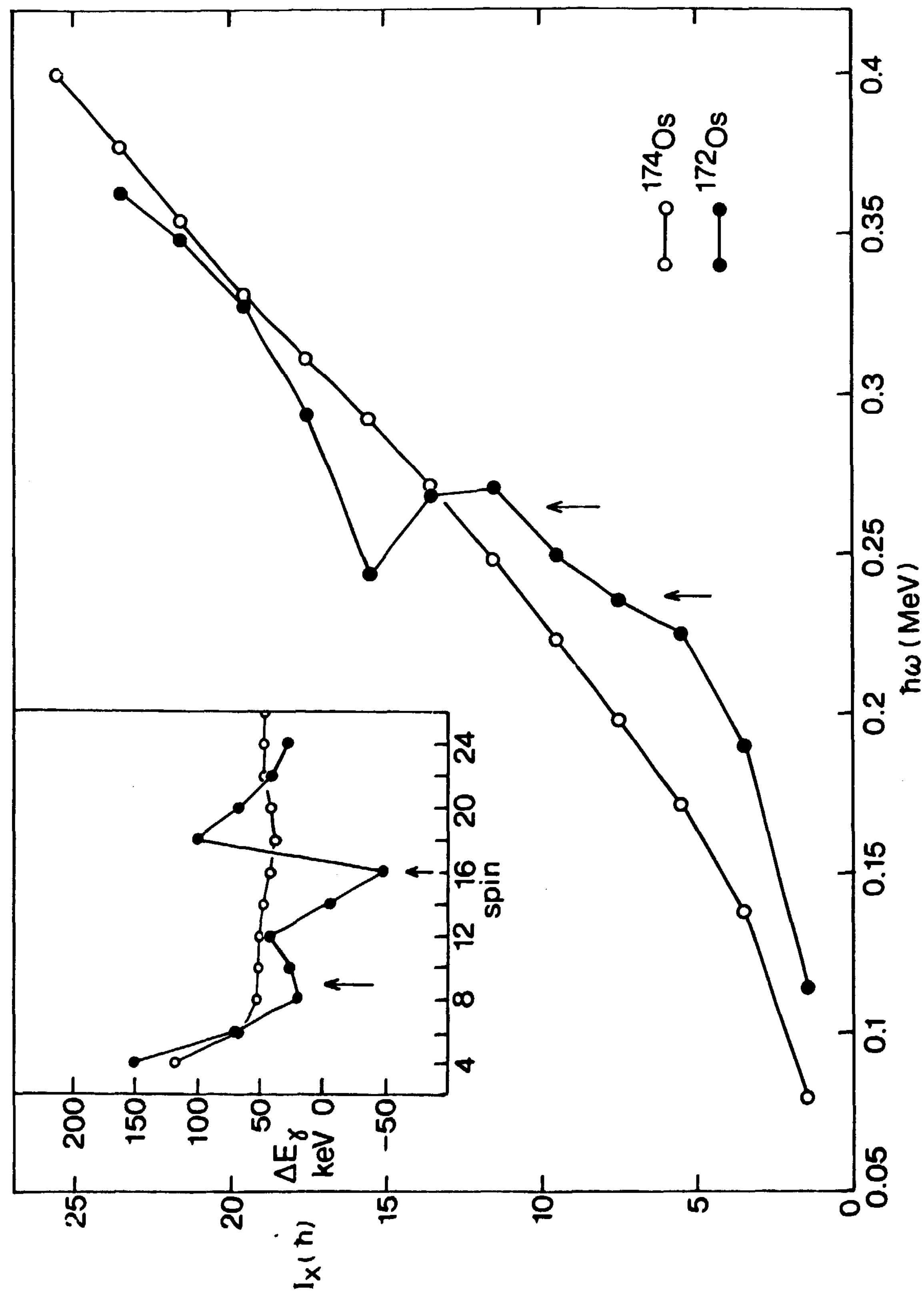
Figure 1 Coincidence γ-ray spectra. The upper spectrum is with an individual gate on the assigned $14^+ \rightarrow 12^+$ yrast transition in ^{174}Os, the lower spectrum with a gate on the assigned $10^+ \rightarrow 8^+$ keV transition in ^{172}Os. The insets show the sum of several gsb gates in each case. In the lower spectrum in ^{172}Os, the intensity of the transitions which follow the 500 gate, in particular the 471 and 449 keV transitions, are not equal in intensity because of the time dependent attenuation of the angular distribution from recoil into vacuum, the observing detector being at 0°.

Figure 2 Total aligned angular momentum I_x, against rotational frequency $\hbar\omega$, for the yrast bands in ^{172}Os and ^{174}Os. The inset shows the difference between successive γ-ray transition energies in ^{172}Os and ^{174}Os. The arrows indicate the position of suggested bandcrossing anomalies in ^{172}Os.



^{174}Os
sum of gsb gates
1000
500
159
276
343
395
446
496
543
gate
584
622
663
708
754
799
0
counts
^{172}Os
500
900
228
379
449
471
488
500
gate
537
541
588
656
698
726
0
100
200
300
400
500
600
700
800
energy (keV)

Figure 1.



^{174}Os
^{172}Os
ħω (MeV)
I_x (ħ)
ΔE$_\gamma$ keV
spin
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0
5
10
15
20
25
200
150
100
50
0
-50
4
8
12
16
20
24

Figure 2.