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R. Vlastou, C. T. Papadopoulos, C. A. Kalfas, S. Kossionides, L. Hildingsson, W. Klamra, Th. Lindbland, C. G. Linden, R. Wyss

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HIGH SPIN STRUCTURE OF ^{173}Os

R. VLASTOU* C.T. PAPADOPOULOS

National Technical University of Athens,

Athens 15773, Greece

C.A. KALFAS and S. KOSSIONIDES

Institute of Nuclear Physics, N.C.S.R. "Demokritos", GR 153 10 Aghia Paraskevi, Greece

L. HILDINGSSON, W. KLAMRA, Th. LINDBLAND,

C.G. LINDEN, and R. WYSS

The Manne Sieghbaahn Institute of Physics, Stockholm, Sweden

Abstract

High-spin states in ^{173}Os have been studied by $\gamma - \gamma$ coincidence measurements following the ^{146}Nd (^{32}S, 5n)^{173}Os reaction. Four main sequences have been identified as the two signature branches of the bands built on the [642] $\frac{5}{2}^+$ and [523] $\frac{5}{2}^-$ Nilsson states. Multipolarity assignements have been derived utilizing the directional correlation (DCO) ratios as well as the anisotropies of the γ-rays. B(M1)/B(E2) ratios have also been extracted to deduce further information on the detailed structure of the bands

* Presented by R. Vlastou

1. Introduction

Nuclei situated in the transitional region between the spherical $Z = 82$ isotopes and the deformed rare earth nuclei provide good testing ground for nuclear models. In this region the nuclear potential becomes soft and the shape of the nuclei can be influenced by the configuration of the excited quasiparticles. For this reason a systematic study was undertaken by several European laboratories (the ESSA-30 collaboration) with the ESSA-30 detector system at the Daresbury Tandem laboratory, which covered nuclei in the region of $A \sim 170$. The aim has to evaluate the structure of the yrast region in these nuclei and to establish the nature of the band crossings. We here present a part of this extensive investigation - the high spin structure of ^{173}Os.

2. Experimental results

High spin states of ^{173}Os were populated through the reaction ^{146}Nd(^{32}S, 5n)^{173}Os The ^{32}S beam of energy 166 MeV was delivered by the Tandem Accelerator at the SERC Daresbury Laboratory. The target consisted of two stacked self-supporting foils of isotopically enriched (98%) ^{146}Nd each of an approximate thickness of 600 $\mu g/cm^2$. At this energy the 4n and 5n (^{174} Os and ^{173} Os) reaction channels were dominant.

The emitted γ-rays were detected with the ESSA - 30 multidetector array of thirty Compton-suppressed germanium detectors, twenty-eight of which were in operation during the present experiment. In this array, six groups, each containing five detectors, were located at the angles 37°, 63°, 79°, 101°, 117° and 143° with respect to the beam direction. The set-up allowed the reaction products to recoil from the target and all the detected γ-rays were therefore prompt and fully Doppler shifted. Recoil nuclei were stopped by a lead stopper outside the detectors system. A ^{152}Eu source was used to obtain the efficiency calibration for the summed spectra of the 28 detectors. The energy calibration was performed by using both the spectra of a ^{152}Eu source and known transitions in ^{174}Os [ref.1].

In order to establish γ-ray cascades and hence the decay scheme, event-by-event coincidence data were recorded and stored on magnetic tapes for subsequent off-line analysis. About 60 million events were gain matched, symmetrized and stored into a 4096 x 4096 channel coincidence matrix.

3. The level scheme

Very little information on the nucleus ^{173}Os was available prior to this experiment. From α-decay measurements of ^{177} Pt, a 91.8 keV transition of ^{173} Os has been established [2]. A 91.3 keV transition has also been observed at Grenoble in the ^{144}Sm + ^{32}S reaction [3] at 205 MeV beam energy in coincidence with Os X-rays, where the reaction products were separated by means of an on-line isotope separator. Recently one sequence of the positive-parity band of ^{173} Os has been reported by Wells et al[4]).

In the present work the identification of Z=76 isotopes was performed by setting gates on the X-rays of Os. The assignement of γ-rays to different isotopes of Os was made by means of excitation function results from short measurements of the ^{144}Sm + ^{32}S reaction at 160, 163 and 170 MeV.

The level scheme of ^{173}Os deduced from these data is shown in Fig.1. The ordering of the transitions is determined by their relative intensities and their coincidence relationships.

Two strong cascades (labelled band 1) together with a set of linking transitions constitute the most intense collective band. Most of the γ-rays within this band were strong enough to provide information concerning their multipolarity assignment by evaluating the anisotropy and DCO ratio.

A $\frac{13}{2}^+$ spin and parity has been assigned to the lower level of this band as expected

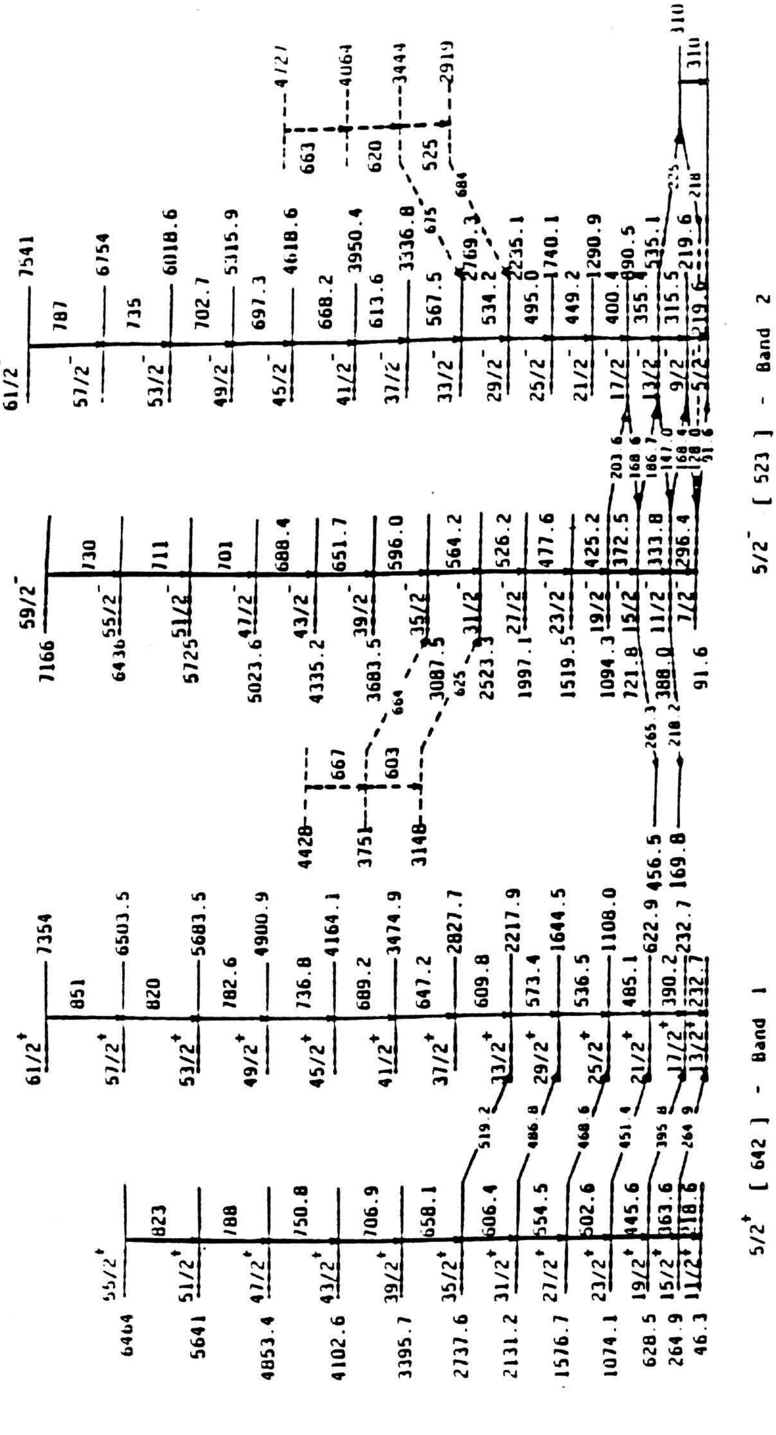

Fig.1 The level scheme of ^{173}Os

both from the features of the band and the systematics of N = 97 isotones. This assignment is in agreement with the one proposed recently by Wells [4]). The favoured and unfavoured members of this band are both present and are extended up to spins $\frac{61}{2}^+$ and $\frac{55}{2}^+$, respectively.

A second collective band (band 2) with an intensity of about half of the preceding one has also been established. It consists of two branches of stretched E2 transitions together with a parallel sequence of weaker ones and a set of less populated linking transitions. All the strong transitions within the band show DCO ratios and/or anisotropies characteristic of stretched quadrupole transitions. From the interband transitions only the 91.6, 128.0 and 168.4 keV γ-rays were strong enough to provide reliable evaluation of the anisotropy.

Based on the features of this band and the known systematics, a band head spin of $\frac{5}{2}^-$ is proposed and thus the two signature components ($\alpha = \frac{1}{2}$ and $\alpha = -\frac{1}{2}$) of band 2 are extended up to spins $\frac{61}{2}^-$ and $\frac{59}{2}^-$, respectively. The positive signature sequence is thought to be the ground state band. This is in agreement with the results of refs.[3,2]. where a γ-ray of 91.6 keV is associated with the de-excitation of ^{173}Os presumably to its ground state. Further a $\frac{5}{2}^-$ ground state is expected from the experimental level systematics of the neighbouring N = 97 isotones ^{171}W [ref.[5]] ^{169}Hf [ref.[6]] and ^{167} Yb [ref.[7]].

Two weak side branches were observed feeding the $\alpha = \frac{1}{2}$ and $\alpha = -\frac{1}{2}$ members of band 2, respectively. Their placement in the level scheme is, however, uncertain due to intensity considerations and to the small number of levels, so they are displayed by dashed lines in Fig.1.

No transitions have been found to connect band 1 and band 2. The relative excitation energy of band 1 could therefore not be determined.

4. Configurations of the Collective Bands at Low Rotational Frequencies

Since almost no information on this nucleus was previously known, the assignments of the two bands are based on Nilsson level systematics and comparisons with other experimental data available in this mass region. For N=97 and β_2 deformation close to 0.2, the neutron Fermi level is situated on the $f_{7/2}[523]\frac{5}{2}$ or $i_{13/2}[642]\frac{5}{2}$ orbitals, the strongly up-sloping $[505]\frac{11}{2}$ configurations from the $h_{11/2}$ shell being reached only for $\beta_2 > 0.33$. For Z=76 the proton Fermi level lies near the top of the $h_{11/2}$ shell and the bottom of the $h_{9/2}$ and $i_{13/2}$ ones, i.e. near the $[514]\frac{9}{2}$, $[541]\frac{1}{2}$ and $[660]\frac{1}{2}$ orbitals, respectively.

For all the configurations discussed in this paper a reference configuration based on a parametrized moment of inertia $J = J_o + J_1\omega^2$ with $J_o = 15$ MeV$^{-1}\hbar^2$ and $J_1 = 90$ MeV$^{-3}\hbar^4$ has been subtracted. The choice of the reference introduces a certain arbitrariness into the extraction of the experimental routhians and alignments.

However by varying the J_o and J_1 parameters within a range representative for several nuclei in this region, it appears that the general trend of these quantities as a function of $\hbar\omega$ is preserved. The values of the Harris parameters used in the present work have been adopted from ref.[4]) for ^{172}Os as they produce an approximately constant value of the rotation alignment i_x at low rotational frequencies.

The two sequencies belonging to band 1 are assigned as the favoured ($\alpha = \frac{1}{2}$) and unfavoured ($\alpha = -\frac{1}{2}$) members of a configuration characterized by a signature splitting indicative of an $i_{13/2}$ neutron lying on the $[642]\frac{5}{2}$ orbital. The $i_{13/2}$ neutron is decoupled from the core as shown in Fig.2 by the large initial aligned angular momentum ($i = 5.5\hbar$). In the neutron Nilsson diagram there is no other high-j orbital able to induce such a large initial alignment at low rotational frequency and moderate deformation. The commonly used A and B labelling for the two lowest-lying quasineutron orbitals from the $i_{13/2}$ shell is used for the two signature branches of band 1.

In contrast to the first structure, band 2 is characterized by the absence of signature splitting. An $f_{7/2}[523]\frac{5}{2}$ neutron configuration is assigned to this $\delta I = 1$ band. It is produced by the coupling of $f_{7/2}$ neutron-holes to the core which explains the absence of splitting and the weak initial alignment ($2\hbar$). The E and F configurations, corresponding to the two lowest-lying quasineutron orbitals from the $f_{7/2}$ shell, are assigned to the two signature partners of band 2.

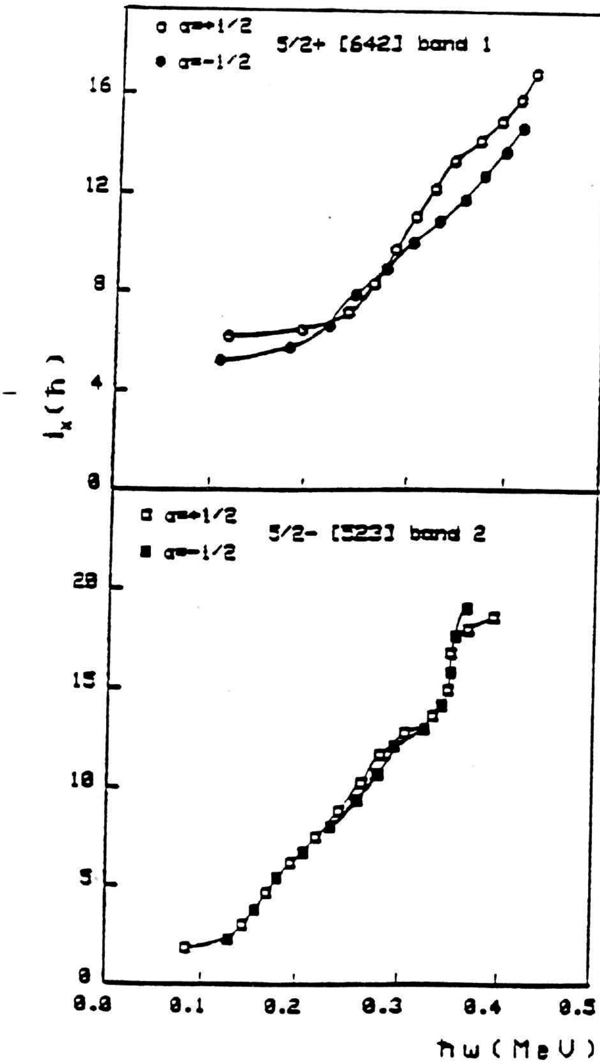

Fig.2 Experimental quasiparticle alignments for bands in ^{173}Os

5. Three and Five-Quasiparticle Configurations

The quasiparticle alignment, i_x, is observed to increase with increasing angular frequency for both bands. However, the variation of i_x as a function of $\hbar\omega$ does not exhibit rapid changes. In first, only gradual upbends have been observed in both cases (fig.2). Similar smooth increase of i_x has also been observed in the yrast-band of ^{174}Os [ref.[8]]. This behaviour is rather expected since the interaction strength between the ground-state band and the S-band and configuration in predicted [9]) to have a strong mass dependence and to be large at this region of Os isotopes.

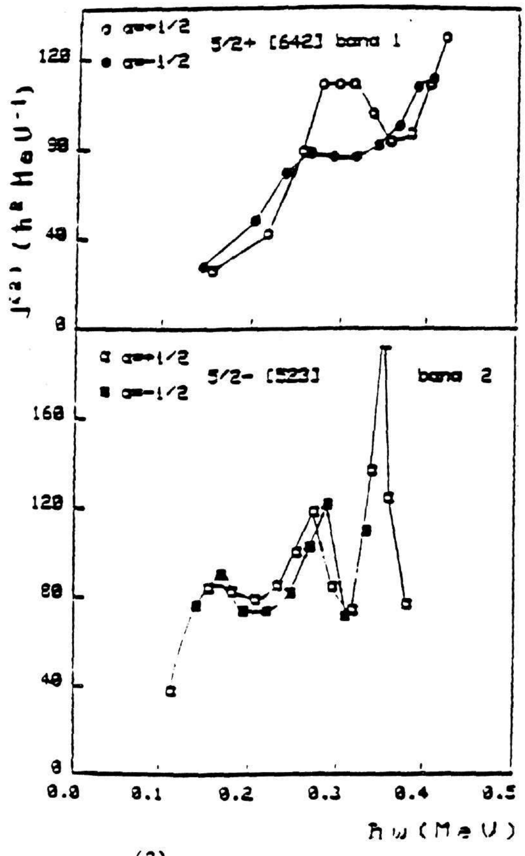

Fig.3 The $J^{(2)}$ second moment of inertia as a function of ħω

The alignment in both signatures of band 1 gains about 8$\hbar$ units in the frequency range 0.20-0.35 MeV. The plot of the second moment of inertia $J^{(2)}$ (fig.3) which is more sensitive to band crossings and independent of the reference configuration reveals a maximum at $\hbar\omega$ = 0.3 MeV for $\alpha = +\frac{1}{2}$ and a shoulder at about 0.27 MeV for $\alpha = -\frac{1}{2}$ signatures. From theoretical calculations of quasiproton and quasineutron routhians it appears that crossing is not compatible with protons. Instead an $i_{13/2}$ neutron alignment is expected for the positive parity band. Due to the blocking of AB crossing, the BC and AD crossings are candidates for the $\alpha = \frac{1}{2}$ and $\alpha = -\frac{1}{2}$ signatures, respectively. The gain in the experimental alignment (8$\hbar$), due to the possible BC and AD neutron crossing, is consistent with the theoretically expected value which is of the order of 9$\hbar$ units.

The experimentally observed gain of alignement, tentatively associated with BC and AD crossings, occurs at frequencies close to the predicted ones. For the AD crossing, the experimental crossing frequency is not well defined in the $J^{(2)}$ plot. However, it seems to occur earlier than the BC crossing. It should be mentioned here that the AD crossing is predicted by the theory to occur above the BC crossing and this is the ordering that has been observed experimentally in the neighbouring N = 97 isotones ^{169}Hf [ref.[9]] and ^{171}W [ref.[10]] where the AD crossing takes place slightly above the BC crossing. On the other hand, behaviour similar to that of ^{173}Os has also been observed in the $i_{13/2}$ bands of heavier Os isotopes, for example ^{177,179}Os [ref.[11]] and ^{175}Os [ref.[12]]. In these isotopes it appears that the alignment in the $i_{13/2}$ bands might be due to AD and BC crossings and these crossings are either degenerate (^{175}Os) or the AD crossing takes place at lower frequency than the BC crossing.

The second moment of inertia increases for both signatures at $\hbar\omega$ = 0.40 MeV and this can be the sign of a second bandcrossing in the two positive-parity bands. Since three neutrons from the $i_{13/2}$ orbital are already decoupled a proton origin of this crossing is more likely. The lowest negative-parity proton orbitals (originating from a mixture of the $h_{9/2}$ and $h_{11/2}$ subshells) are predicted to align at $\hbar\omega = 0.5$ MeV. A proton crossing is, therefore, proposed at $\hbar\omega \geq 0.40$ MeV.

The alignment i_x in both sequences of band 2, starts to increase regularly from $\hbar\omega = 0.1$ MeV and gains about $10\hbar$ units as it reaches $\hbar\omega = 0.35$ MeV and then gains rapidly another $6\hbar$ units. As for band 1, information concerning band crossings has to be extracted from the $J^{(2)}$ moment of inertia (fig.3): small peaks show up at 0.17 MeV rotational frequency for both signatures, followed by a stronger one at 0.28 and 0.29 MeV for $\alpha = +\frac{1}{2}$ and $\alpha = -\frac{1}{2}$ signatures, respectively. This indicates that two alignments occur in the experimentally observed frequency range. This kind of effect is not unique. A similar situation has also been observed in ^{172}W [ref.[13]], ^{172}Os [ref.[4]] ^{174}Os [ref.[14]] and ^{176}Pt [ref.[15]]. The low spin anomalies found in these isotopes have been tentatively interpreted in terms of a three band mixing analysis. An intruder $h_{9/2}$ proton band, however, influencing the yrast band at low spin, would imply a significant rise of B(M1)/B(E2) values. In ^{173}Os, the experimental B(M1)/B(E2) ratios, as described in detail in sect.6, show a pronounced decrease with increasing rotational frequency, consistent with neutron rather than proton alignment at low rotational frequencies. The alignment of $i_{13/2}$ quasineutron pair is thus considered to be responsible for the first anomaly of the ground state band at 0.17 MeV.

The three-quasiparticle band appears then to be crossed by a five-quasiparticle band at 0.28 MeV. The second peak in fig.3 may be due to the intersection of two bands of different $(\nu i_{13/2})^2$ configurations, since the protons are expected to become important above 0.4 MeV.

The gain of $6\hbar$ units of alignment at 0.35 MeV, which corresponds to the strong peak in the $J^{(2)}$ plot of fig.3, should be attributed to rotation alignment of an $h_{9/2}[541]\frac{1}{2}$ quasiproton pair or a mixed alignment ot two quasiprotons occupying the $h_{9/2}[541]\frac{1}{2}$ and $h_{11/2}[514]\frac{9}{2}$ levels.

6. B(M1)/B(E2) ratios

Additional information on the nuclear structure of the bands can be gathered from measurements of the competition between M1 and E2 transitions within the $\Delta I = 1$ bands. Values of the reduced transition probabilities B(M1)/B(E2) could be extracted, using the formula:

$$\frac{B(M1; I \rightarrow I-1)}{B(E2; I \rightarrow I-2)} = 0.693 \frac{I_\gamma(M1)}{I_\gamma(E2)} \frac{E_\gamma^5(E2)}{E_\gamma^3(M1)} \frac{1}{1+\delta^2}$$

where the γ-ray intensities have been determined from coincidence gates to avoid contamination effects, and the E2/M1 mixing ratio δ for the $\Delta I = 1$ transitions can approximately be set to zero. The extracted ratios for both band 1 and band 2 of ^{173}Os are presented in fig.4. These experimentally deduced B(M1)/B(E2) ratios can be compared to theoretically estimated values for specific configurations, obtained from the semiclassical

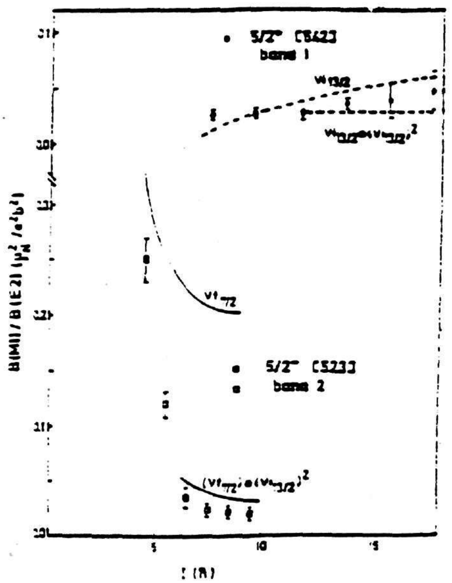

Fig.4 Experimental B(M1;I → I-1)/B(E2;I → I-2) values for the two bands of ^{173}Os. The solid and open data points refer to ΔI=1 transitions from α = -1/2 to α = +1/2 and α = +1/2 to α = -1/2 decay sequencies respectively. The solid and dashed lines are model predictions in which gradual neutron alignment is taken into account.

formula[16,17]):

$$\frac{B(M1; I \rightarrow I-1)}{B(E2; I \rightarrow I-2)} = \frac{12}{5Q_o^2 cos^2(\gamma + 30^o)}\{1 - \frac{K^2}{(I-\frac{1}{2})^2}\}^{-2}\frac{K^2}{I^2} \times [(g_1 - g_R)((I^2 - K^2)^{1/2} - i_1) - (g_2 - g_R)i_2]^2 \quad (1)$$

where g_1 and i_1 are the gyromagnetic factor and alignment for the strongly coupled quasiparticle while g_2 and i_2 refer to aligned quasiparticles. The alignment values were taken from the experimentally extracted i_x of fig.2. For the quadrupole moment the value of Q_o = 7.7 e.b, experimentally deduced for ^{174}Os [ref.[14]], was used. The deformation parameter γ was approximately set to zero since the TRS calculations do not indicate any significant variation of γ from zero within the range of observed rotational frequencies. For the theoretical parameters, the g-factors given by the Schmidt limits with $g_s = 0.6 g_s$ (free) and $g_R = 0.4$ were used throughout the calculations. The theoretical predictions based on eq.(1) are illustrated by solid and dashed lines in fig.4 in comparison with the experimental B(M1)/B(E2) ratios. An increase in the ratio of the reduced transition probabilities can be due both to an increase in the M1 transition strength and to a loss of collectivity. However there is no indication of significant shape changes in ^{173}Os. Therefore the contribution of the B(E2) value to the rise of the ratio should be negligible. Any variation of the B(M1)/B(E2) ratio can thus be attributed to the alignment of a pair of quasiparticles which is expected to influence the B(M1) values. Because of the opposite signs of the proton versus neutron g-factors, a mixed ($\pi \otimes \nu$) configuration adds up constructively and exhibits enhanced M1 transitions, whereas a ($\pi \otimes \pi$) or ($\nu \otimes \nu$) configuration is expected to quench the M1 transition strength relative to the case of only a single quasiparticle.

The ratios of the reduced transition probabilities for the [523]$\frac{5}{2}^-$ band, shown in fig.4, exhibit a pronounced decrease by a factor of 10 at spin $\frac{13}{2}^-$. This is the place where the first peak in the experimental $J^{(2)}$ (fig.3) and the first alignment gain (fig.2) appear. The observed trend can only be reproduced by the theory if the gradual alignment gain is attributed to a pair of $i_{13/2}$ neutrons. Thus, the experimental decrease in the B(M1)/B(E2) ratio of the 5/2[523] band is in agreement with the above proposed neutron origin of the first anomaly observed in the second moment on inertia $J^{(2)}$ at $\hbar\omega = 0.16$MeV.

The B(M1)/B(E2) ratios of the [642]$\frac{5}{2}^+$ band to not exhibit any rapid changes, as can be seen in fig.4, and cannot provide an unambiguous explanation for the gradual increase of alignment at low rotational frequencies. The smooth variation of the ratio can be reproduced equally well by the single $i_{13/2}$ neutron configuration over the observed spin range or by considering a gradual alignment of a pair of $i_{13/2}$ neutrons at spin $\frac{23}{2}^+$, where the upbend in the alignment plot (fig.2) starts to occur.

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