Eur. Phys. J. A **19**, 319–325 (2004)
DOI 10.1140/epja/i2003-10131-2

THE EUROPEAN PHYSICAL JOURNAL A

Electromagnetic properties of pseudo-Nilsson bands in ^{185}Os

C. Wheldon[1,2,a], A.E. Stuchbery[3], A.N. Wilson[3], G.D. Dracoulis[3], A.M. Bruce[4], R.A. Bark[3,b], A.P. Byrne[3,5], F.M. Prados-Estevez[4], G.J. Lane[3], C.-B. Moon[3,6], J.N. Orce[4,c], and R. Wood[1]

[1] Department of Physics, University of Surrey, Guildford, Surrey GU2 7XH, UK
[2] Kernphysik II, Gesellschaft für Schwerionenforschung, Max-Planck-Straße 1, D-64291 Darmstadt, Germany
[3] Department of Nuclear Physics, Research School of Physical Sciences and Engineering, The Australian National University, Canberra, ACT 0200, Australia
[4] School of Engineering, University of Brighton, Brighton BN2 4GJ, UK
[5] Joint appointment with Department of Physics, The Faculties, Australian National University, Canberra ACT 0200, Australia
[6] Department of Physics, Hoseo University, Chung-Nam 336-795, Republic of Korea

Received: 19 August 2003 /
Published online: 27 January 2004 –
Communicated by J. Äystö

Abstract. New data have been obtained for ^{185}Os following the ^{176}Yb(^{13}C,4n)^{185}Os reaction, extending the pseudo-Nilsson $\frac{1}{2}^-, \frac{3}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ doublet structure and the $\frac{7}{2}^-[\tilde{4}\tilde{0}\tilde{4}]$ band to significantly higher spins. Gamma-ray branching ratio data have been analysed to obtain extensive $B(M1)$ and $B(E2)$ ratios for intraband and interband transitions. The data are compared with particle-rotor calculations based on the pseudo-Nilsson potential and the Woods-Saxon potential. The results indicate that the pseudo-Nilsson approximation provides a good description of the $\frac{1}{2}^-$, $\frac{3}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ bands up to the first band crossing; the difference in magnitude between the model predictions and data for the $\frac{7}{2}^-[\tilde{4}\tilde{0}\tilde{4}]$ band may be attributed to a lower deformation for the higher-K structure.

PACS. 21.60.-n Nuclear structure models and methods – 21.10.Re Collective levels – 23.20.Lv γ transitions and level energies – 27.70.+q $150 \leq A \leq 189$

1 Introduction

Interest in pseudo-spin symmetry first arose in spherical nuclei due to the observation of nearly degenerate single-particle states of the same parity and having $\Delta j = 1$ and $\Delta l = 2$, where j is the total angular momentum and l is the orbital angular momentum [1,2]. The pseudo-spin scheme involves the introduction of a pseudo-orbital angular momentum, $\tilde{l} = l - 1$, so that the pairs of degenerate orbits obey the relation $j = \tilde{l} + 1/2$ and $j' = \tilde{l} - 1/2$. Much of the interest in the pseudo-spin scheme as a calculational tool stems from the fact that the pseudo-spin–orbit interaction is so small compared with normal spin-orbit interactions that it can be neglected.

In deformed systems, pseudo-spin symmetry gives rise to pairs of Nilsson orbits with $\Delta\Omega = 1$ and $\Delta\Lambda = 2$ that are nearly degenerate as a function of deformation. Explicitly, the pseudo-spin partner orbits have the asymptotic Nilsson quantum numbers $\Omega[Nn_z\Lambda - 2]$ and $\Omega'[Nn_z\Lambda]$, where $\Omega = (\Lambda - 2) + \frac{1}{2}$ and $\Omega' = \Lambda - \frac{1}{2}$. The pseudo-spin transformation maps these orbits on to pseudo-Nilsson orbits with the quantum numbers $\tilde{N} = N - 1$, $\tilde{\Lambda} = \Lambda - 1$ and $\tilde{\Omega} = \Omega$, so that the nearly degenerate bands have $\tilde{\Omega} = (\tilde{\Lambda} \pm \frac{1}{2})[\tilde{N}\tilde{n_z}\tilde{\Lambda}]$.

A number of doublet band structures in the $A =$ 180–190 mass region have been interpreted in terms of the pseudo-spin scheme. Cases where structures have been observed that resemble pseudo-Nilsson doublet structures include the odd-N nuclei ^{187}Os [3–5] and ^{189}Os [5,6], the odd-Z nucleus ^{175}Re [7], and odd-odd nuclei such as ^{176}Re [8].

Previous studies of the Os isotopes in the pseudo-spin scheme have focused on comparisons of excitation energies along with $E2$ transition rates and branching ratios [3–5]. These observables provide a somewhat indirect test of the approximations associated with the pseudo-spin approach through their dependence on the pseudo-Coriolis mixing. In contrast, because the $M1$ operator depends on the single-particle angular-momentum operators, intraband

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[a] *Present address*: Hahn-Meitner-Institute, Glienicker Straße 100, D-14109 Berlin, Germany; e-mail: `wheldon@hmi.de`
[b] *Present address*: iThemba LABS, Faure, ZA-7131, South Africa.
[c] *Present address*: Department of Physics and Astronomy, Physics-Chemistry Building CP65, University of Kentucky, Lexington, KY 40506 USA.

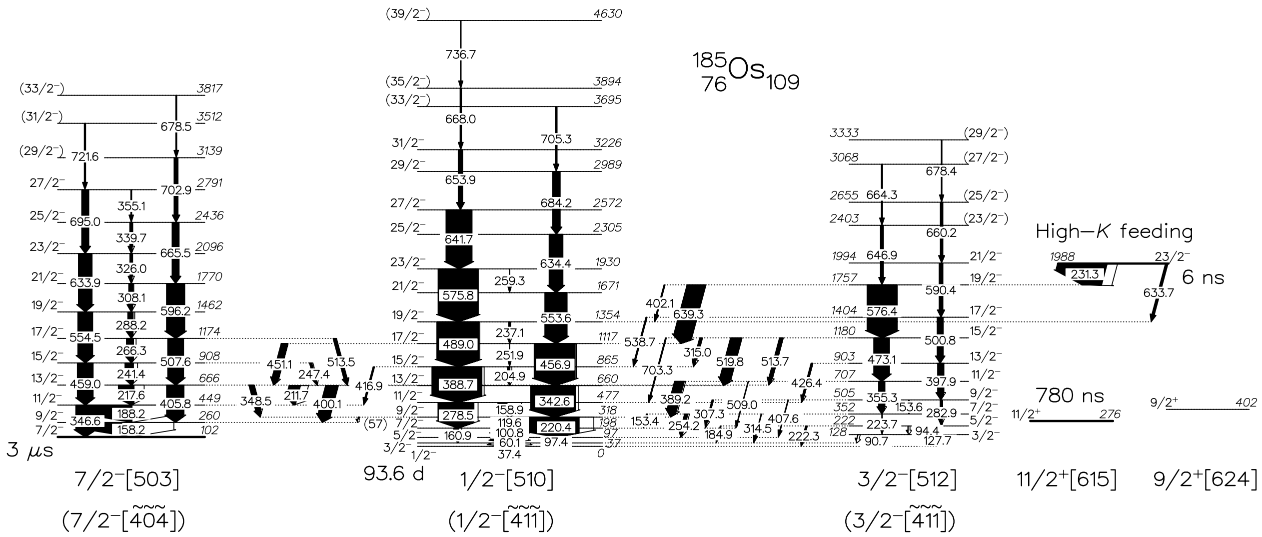

Fig. 1. Partial level scheme for the $\frac{1}{2}^-[510]$ ground-state band, together with the $\frac{3}{2}^-[512]$ 1-quasiparticle band (with pseudo-Nilsson labels) in ^{185}Os observed in the current work. The other known 1-quasiparticle bandheads [9] are shown for completeness together with the state at 1988 keV through which the majority of the high-K structures feed [10]. Tentative spin and parity assignments are given in parentheses. The arrow widths are proportional to γ-ray (black) and internal electron conversion (white) intensities. All energies are quoted in keV. Half-lives are given for some states where greater than 5 ns.

and interband $M1$ transition rates are much more sensitive tests of the approximation, including the effects of the pseudo-spin mapping of the single-particle structure as well as the strength of the pseudo-Coriolis interactions.

This paper reports new experimental information on ^{185}Os, which includes more extensive data than obtained hitherto on $M1$ transitions within and between the $\frac{1}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ ($\frac{1}{2}^-[510]$) and $\frac{3}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ ($\frac{3}{2}^-[512]$) pseudo-spin bands. The higher-K $\frac{7}{2}^-[503]$ (or $\frac{7}{2}^-[\tilde{4}\tilde{0}\tilde{4}]$) band is also observed. The data on these bands allows for extensive comparisons with particle-rotor calculations based on the pseudo-Nilsson potential, which are reported here. Particle-rotor calculations based on the Woods-Saxon potential were also performed to provide a reference to the more conventional approach. Other aspects of the structure of ^{185}Os will be presented in a forthcoming manuscript [11].

2 Experimental method

A 63 MeV ^{13}C beam, provided by the 14UD Pelletron Tandem accelerator at the Australian National Laboratory, was incident on a 4.1 $\mathrm{mg\,cm^{-2}}$ self-supporting foil of ^{176}Yb. The fusion-evaporation reaction led to the formation of high-spin states in the residual nuclei. The 4n channel leading to ^{185}Os dominated the products with the next two strongest contaminants being the 3n and 5n channels leading to the well-studied nuclei ^{184}Os [12,13] and ^{186}Os [14], respectively. This reaction has not previously been used to synthesise ^{185}Os. The CAESAR array of 6 Compton-suppressed co-axial Ge detectors and 2 unsuppressed LEPS was used to record the γ-ray events. The co-axial detectors were arranged in pairs at angles of $\pm 48°$, $\pm 97°$ and $\pm 145°$ to the beam axis. The LEPS were located at 45° and 135°. Four days of γ-γ coincidence data were recorded using a beam structure consisting of a 1 ns wide bunched beam followed by 1711 ns in which the beam was swept off.

The partial level scheme shown in fig. 1 was constructed from γ-γ and γ-γ time coincidences and DCO ratios and the properties of the newly extended 1-quasiparticle structures are discussed below.

3 Results

The $\frac{1}{2}^-[510]$ ($\frac{1}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$) ground-state band has been previously identified up to a tentative spin and parity of $I^\pi = (25/2^-)$ [3]. This has been extended in the current work to $I^\pi = (39/2^-)$ and $(33/2^-)$, in the favoured and unfavoured signatures, respectively, with firm assignments, made up to $31/2^-$. Three additional $M1/E2$ branches have been observed de-populating the 17/2, 19/2 and 23/2 members of the ground-state band.

The spins and parities of the $\frac{3}{2}^-[512]$ ($\frac{3}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$) band had earlier been measured up to $I^\pi = (19/2^-)$ [10] in the favoured signature. Two states ($(5/2^-)$ and $(9/2^-)$) were tentatively placed in the unfavoured signature [3,15]. In the current work the band members up to $I^\pi = (29/2^-)$ have been identified.

The $\frac{7}{2}^-[503]$ ($\frac{7}{2}^-[\tilde{4}\tilde{0}\tilde{4}]$) structure is built on an isomeric bandhead with $t_{1/2} = 3.0$ μs [3,9]. The bandhead decay via a 5 keV transition to the $5/2^-$ level of the $K^\pi = 1/2^-$ band ($K = \sum_i \Omega_i$, for i unpaired particles) has been inferred from coincidence data, but not yet observed. The $K^\pi = 7/2^-$ band has been extended from the $(19/2^-)$

level at 1462 keV [3], up to $I^\pi = (33/2^-)$ with intra-band $\Delta I = 1$ transitions observed to de-populate the band members up to and including the $27/2^-$ state.

The identification of previously unknown transitions, including $M1$ decays, both within and between the $K^\pi = 1/2^-$, $3/2^-$ and $7/2^-$ pseudo-spin structures, enables a more rigorous test of the pseudo-Nilsson symmetry in the $A \approx 180$ region to be made. Importantly, to higher spins than previously observed and specifically for neutrons, to higher K values. This is implemented using comparisons of reduced transition probabilities to theoretical predictions as described below. Note that for all of the experimental $B(M1)$ transition rates a quadrupole/dipole mixing ratio, $\delta = 0$, is assumed. Setting $\delta \neq 0$, using the rotational model expressions [16] causes a reduction of $< 2\%$ in the $B(M1)/B(E2)$ for the $K^\pi = 1/2^-$ band, for example.

4 Particle-rotor calculations

The pseudo-Nilsson approach has provided a good description of low-spin states in ^{187}Os [3–5] and ^{189}Os [5,6]. The present results provide an opportunity to examine extensive branching ratio data in the more neutron-deficient isotope ^{185}Os. In this nucleus, competing $M1$ and $E2$ transitions are observed both within and between the $\frac{1}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$, $\frac{3}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ pseudo-Nilsson partners up to high spins. In addition, the observation of one half of the $[\tilde{4}\tilde{0}\tilde{4}]$ doublet (the $\frac{7}{2}^-[503]$ band) in the same nuclide allows the study of a higher-K neutron orbital than has been previously considered in the pseudo-Nilsson approach.

A series of calculations have been performed using the pseudo-Nilsson model [17]. Calculations using the "normal" Woods-Saxon particle-rotor approach [18] were also carried out, to provide a benchmark for comparison with the results obtained in the pseudo-Nilsson approximation. Some details regarding the calculations are given in the following subsections.

4.1 Pseudo-Nilsson calculations

The pseudo-Nilsson code of ref. [17] was used to calculate level energies and reduced transition probabilities ($B(M1)$ and $B(E2)$ rates) for states in ^{185}Os up to an excitation energy of 3.0 MeV. The calculations follow a standard particle-rotor formalism, but employ the pseudo-Nilsson potential in the form described by Troltenier *et al.* [19] in place of the normal Nilsson or Woods-Saxon potential. The full $\tilde{N} = 4$ pseudo-Nilsson oscillator shell is included.

Several calculations were performed to test the sensitivity of the predicted transition rates to the model parameters, especially the quasiparticle energies and the strength of the Coriolis interaction. The calculations were carried out for fixed deformation, $\tilde{\delta} = 0.24$ ($\varepsilon_2 = 0.204$). A rotational g-factor of $g_R = 0.28$ [20] and an intrinsic quadrupole moment $Q_0 = 5.6$ $e{\cdot}b$, interpolated from the values in the neighbouring even-even osmium isotopes [12,14], were assumed, and the intrinsic spin g-factors, g_Σ, were attenuated from their "free" values by a factor of 0.7. The pair gap was set to $\Delta = 12/\sqrt{A}$ MeV. The calculated in-band level energies depend on a moment-of-inertia parametrisation in the form of an expansion in $I(I+1)$. It was found that an expansion to first order with moment-of-inertia parameter $A = 14.85$ keV gave a reasonable fit to the energies of the $\frac{1}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ band. The same moment-of-inertia parameter is applied to all structures in the calculations.

Initially, a set of "as is" calculations (in which the single-quasiparticle energies were prescribed by the pseudo-Nilsson potential) were carried out for values of the Coriolis attenuation factor, χ, ranging from $\chi = 1.0$ (no attenuation), to $\chi = 0.0$ (complete attenuation). In subsequent calculations, the quasiparticle energies were artificially adjusted in order to reproduce the experimentally measured bandhead energies for each of the $\frac{1}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$, $\frac{3}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ and $\frac{7}{2}^-[\tilde{4}\tilde{0}\tilde{4}]$ structures.

4.2 Woods-Saxon

Particle-rotor calculations using a Woods-Saxon potential [18] were also performed. For these calculations, Woods-Saxon deformation parameters $\beta_2 = 0.208$ and $\beta_4 = -0.052$ were used, which were interpolated from the values given for ^{184}Os and ^{186}Os in ref. [21]. Axial deformation was assumed and the standard formulation of the pairing strengths [18] was adopted. In this model, the intrinsic quadrupole moment is determined by the potential parameters and was found to be $Q_0 = 5.76$ $e{\cdot}b$, which is close to that used in the pseudo-Nilsson calculations. The moment of inertia of the calculated bands must be specified by the energy of the first 2^+ state: for the present calculations, this was taken to be $E(2^+) = 89.1$ keV, which is equivalent to the moment of inertia used in the pseudo-Nilsson calculations. It is not possible to alter the quasiparticle energies in the Woods-Saxon code. Thus, only one set of calculations was performed, in which the Coriolis interaction was not attenuated.

5 Discussion

5.1 Level energies

As the degree of Coriolis mixing between the pseudo-Nilsson states depends in part on the differences in energy between levels in the doublets, reasonable agreement between calculated and observed level energies was sought before more detailed comparisons of electromagnetic properties were made.

In the pseudo-Nilsson model, the Nilsson orbits $\frac{1}{2}^-[510]$ and $\frac{3}{2}^-[512]$ orbitals make up the $\tilde{\Omega} = \frac{1}{2}$ and $\tilde{\Omega} = \frac{3}{2}$ members of the $[\tilde{4}\tilde{1}\tilde{1}]$ doublet. Thus, the initial set of calculations, in which the quasiparticle energies were not adjusted to fit the data, predict the two bandheads to be almost degenerate. The levels are within 5 keV of each other for all values of the Coriolis interaction strength, but the $\frac{3}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ bandhead is predicted to be the ground state by the calculations with $\chi = 1.0$. Experimentally, the $\frac{1}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ bandhead is observed as the ground state and the $\frac{3}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ bandhead lies at 128 keV. Similarly, if the pseudo-spin symmetry were exact, the $\frac{7}{2}^-[503]$ would be one half of the $[\tilde{4}\tilde{0}\tilde{4}]$ doublet, with the $\frac{9}{2}^-[505]$ orbital as its partner. The calculations with $\chi = 0.0$ predict the $\frac{7}{2}^-[\tilde{4}\tilde{0}\tilde{4}]$ bandhead at an excitation energy of 173 keV with its $\tilde{\Omega} = \frac{9}{2}$ partner 15 keV higher, and again the higher-$\tilde{\Omega}$ bandhead is brought lower for $\chi = 1.0$. Experimentally, the $\frac{7}{2}^-[\tilde{4}\tilde{0}\tilde{4}]$ bandhead is observed at 102 keV, while its partner is not observed. All other pseudo-Nilsson states, which are based on natural-parity single-quasiparticle excitations, are calculated to lie at least 1 MeV above yrast, and therefore have negligible effect on the properties of the low-lying states.

Calculations were then performed in which the quasiparticle energies were adjusted to reproduce the $\frac{1}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$, $\frac{3}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ and $\frac{7}{2}^-[\tilde{4}\tilde{0}\tilde{4}]$ bandhead energies. The Coriolis attenuation factor was again varied between 0.0 and 1.0. It was found that the level energies (and signature splitting) of the $\frac{1}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ band were best reproduced with $\chi = 0.6$, which gave energies correct to within 25 keV up to spin $I = 21/2\hbar$. (It should be noted that the moment-of-inertia parameter was derived from this band.) As an alignment takes place in both signatures of this band at $I \approx 23/2\hbar$, it is not meaningful to compare level energies above this point. The calculations for the $\frac{3}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ and $\frac{7}{2}^-[\tilde{4}\tilde{0}\tilde{4}]$ show that the degree of signature splitting in these bands is fairly well reproduced with $\chi = 0.6$. However, in terms of absolute level energies, the model does progressively worse with increasing spin, so that the $I = 21/2\hbar$ level of the $\frac{3}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ band is under-predicted by 150 keV and the $I = 21/2\hbar$ level in the $\frac{7}{2}^-[\tilde{4}\tilde{0}\tilde{4}]$ band by 200 keV. This failure to reproduce the level energies may arise from differences in the moments of inertia between the three structures, which cannot be allowed for within the present calculational approach.

The standard Woods-Saxon particle-rotor calculations predict the $\frac{1}{2}^-[510]$ ($\frac{1}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$) bandhead to be the ground state. The $\frac{3}{2}^-[512]$ ($\frac{3}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$) bandhead is predicted at 70 keV, which is somewhat lower than the 128 keV observed experimentally, while the $\frac{7}{2}^-[503]$ ($\frac{7}{2}^-[\tilde{4}\tilde{0}\tilde{4}]$) bandhead is predicted at 197 keV, compared to the experimental value of 102 keV. These predictions are significantly better than those of the pseudo-Nilsson calculations in which the quasiparticles energies were not artificially adjusted. As the quasiparticle energies cannot be adjusted to fit the bandheads within this model, it cannot be expected that the higher-spin levels will be well reproduced. However, the predicted degree of signature splitting can be compared with experiment: with $\chi = 1.0$, the signature splitting is over-estimated for both the $\frac{1}{2}^-[510]$ and $\frac{3}{2}^-[512]$ bands, but is well reproduced for the higher-K $\frac{7}{2}^-[503]$ band. In general, the level energies predicted by the Woods-Saxon calculations are within 200 keV of the observed levels up to $I = 21/2\hbar$.

5.2 Branching ratios

The results of the two sets of pseudo-Nilsson calculations described above (with and without adjustment of the bandhead energies) indicated that the wave functions are not, in fact, strongly dependent on the quality of fit to the level energies. As is expected, the largest differences occur for the calculations with the full Coriolis strength. In these cases, adjusting the quasiparticle energies changes the predicted transitions rate ratios by at most a factor of two and on average $\approx 30\%$. Thus, the results obtained without adjusting the quasiparticle energies exhibit the same features as those obtained with more realistic level energies. This suggests that the intrinsic structure of the levels is much more important than the precise level of Coriolis mixing, which is affected by the relative excitation energies.

Although the calculations yield absolute reduced transition probabilities for all possible transitions between levels in the pseudo-Nilsson scheme, the lack of level lifetime information in the present data means that comparisons are limited to ratios of transitions de-exciting specific levels. Branching ratios for transitions within and between the $\frac{1}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ and $\frac{3}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ bands predicted by the pseudo-Nilsson calculations are shown in fig. 2. The values calculated with Coriolis attenuation factors $\chi = 1.0$ and $\chi = 0.6$ (which was found to best reproduce the level energies) are shown as solid and dotted lines, respectively. The predictions of the Woods-Saxon calculations are shown for comparison (dot-dashed lines).

The top left panel of fig. 2 shows the experimental and calculated intraband reduced transition-rate ratios for the $\frac{1}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ band. The staggered pattern, with larger $B(M1)/B(E2)$ values observed from states in the $\alpha = \frac{1}{2}$ signature, is similar to the pattern observed in the corresponding band in the isotone ^{183}W. Pseudo-Nilsson calculations performed for that case [17] are in close agreement with the available data. In the present case, the phase of the staggering is reproduced and there is reasonable quantitative agreement up to spin $I = 19/2$, with both data and calculations showing a gradual decrease in the ratios. The pseudo-Nilsson calculations reproduce the data best if there is no attenuation of the Coriolis interaction. The rate at which the predicted $B(M1)/B(E2)$ values decrease with increasing spin is over-estimated by these calculations. In comparison, the normal Woods-Saxon particle-rotor calculations reproduce the rate of reduction somewhat better, but consistently over-estimate the actual magnitude. The over-prediction by the pseudo-Nilsson calculations of the $B(M1)/B(E2)$ at $I = 23/2\hbar$ is the result of an accidental degeneracy in the calculated level energies.

Both the Woods-Saxon and pseudo-Nilsson calculations fail to reproduce the absolute magnitudes of the in-band $B(M1)/B(E2)$ ratios for the $\frac{1}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ band at

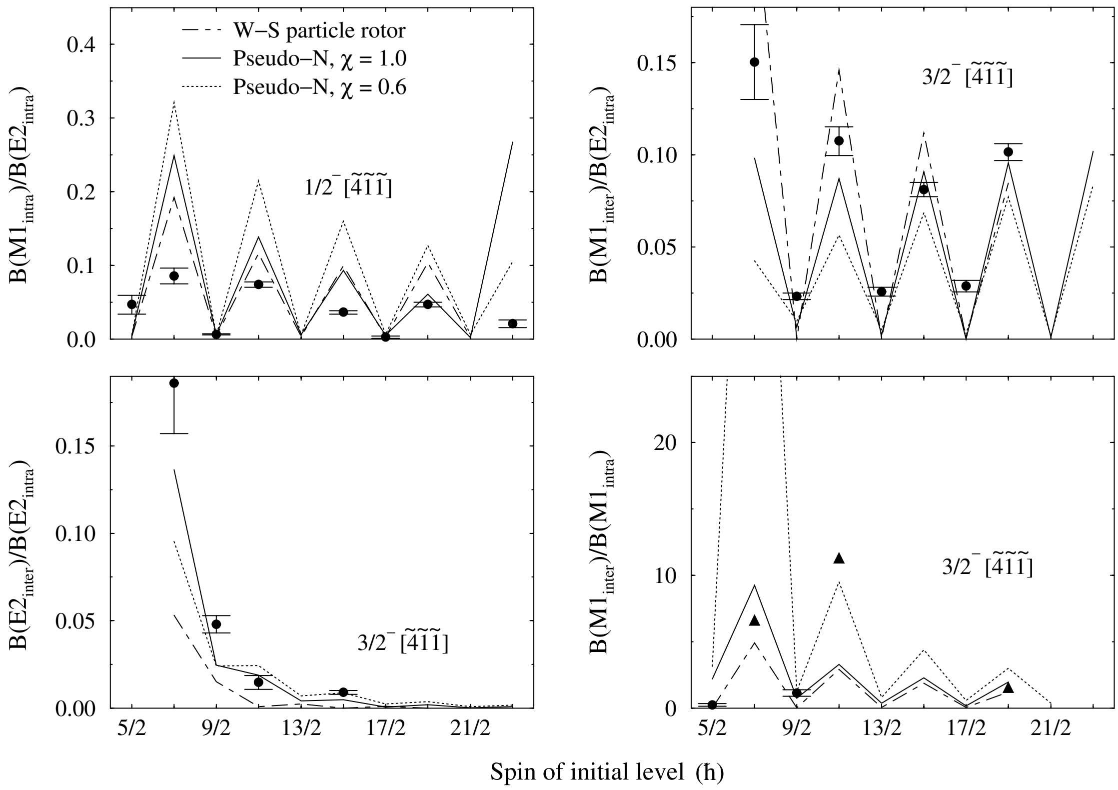

Fig. 2. Comparison of observed (filled circles) and calculated (lines) transition ratios for the intraband and interband transitions from levels in the $\frac{1}{2}^-$ and $\frac{3}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ bands in ^{185}Os. Lower limits are given (filled triangles) for some ratios. In all cases involving interband decays, these are stretched transitions to the $\frac{1}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ pseudo-partner band. The solid and dotted lines represent the results of pseudo-Nilsson calculations for $\chi = 1.0$ and 0.6, respectively. The dot-dashed lines are the results of "standard" Woods-Saxon calculations for $\chi = 1.0$. See the text for details. The $B(M1)/B(E2)$ ratios are in units of $[\mu_N^2/(e\cdot b)^2]$.

low spins: in fact, the data cannot be reproduced unless unrealistic values of the g-factor and quadrupole-moment parameters are adopted. This may be related to the over-estimation of the ground-state g-factor in the isotone ^{183}W by pseudo-Nilsson, Nilsson and Woods-Saxon models [17,22]. It has been suggested [17] that this failure is due to problems with the theoretical magnetic decoupling parameter, rather than the intrinsic g-factor, and that the same general problem is responsible for the over-estimation of the magnetic moments of the $\frac{1}{2}^-[510]$ ground states in ^{187,189}Os by Nilsson and Woods-Saxon models [22].

Figure 2 (top right) shows the $B(M1)/B(E2)$ ratios for interband $M1$ and in-band $E2$ transitions for the $\frac{3}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ band. The interband $M1$ transitions are to the $\frac{1}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ pseudo-partner band. Again, the phase and magnitudes are reproduced well by the pseudo-Nilsson calculations with $\chi = 1.0$. The success of the pseudo-Nilsson calculations is comparable to that of the Woods-Saxon model. The branching ratios for transitions out of the unfavoured signature are consistently under-estimated by both types of calculation, but this may be explained by considering the $E2$ component of the $\Delta I = 1$ transitions, which was ignored in obtaining the experimental branching ratios. Indeed, the calculations indicate a non-negligible probability for $\Delta I = 1$ $E2$ transitions from the unfavoured signature of the $\frac{3}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ band to levels in the $\frac{1}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$, which would result in a larger intensity of the observed γ-ray transitions.

The bottom left panel of fig. 2 shows $B(E2)/B(E2)$ ratios for interband/in-band transitions from the $\frac{3}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ structure. The pseudo-Nilsson calculations with $\chi = 1.0$ successfully reproduce the data, with the interband $B(E2)$s falling off rapidly as the angular momentum increases. For these ratios, the Woods-Saxon calculations significantly under-predict the transition-rate ratios. Closer inspection of the calculations suggests that it is the interband $E2$ rates that are under-estimated, as the in-band rates are similar to those predicted by the pseudo-Nilsson model, and are used in the successful reproduction of the data shown in the top right panel of fig. 2. As the interband $E2$ transition rates are a direct measure of the Coriolis mixing, this difference between the models probably stems from the fact that the mixing can be stronger in the pseudo-Nilsson approximation.

The corresponding plot for the (limited) data for the $M1$ transitions is shown in fig. 2 (bottom right). The observation of only 2 intraband transitions in the $\frac{3}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ band makes conclusions from these data difficult, but lower limits were obtainable for $I = 7/2$, 11/2 and 19/2 $\hbar$

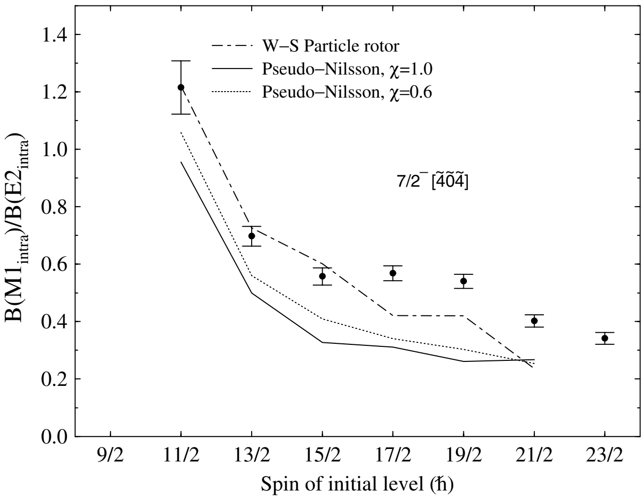

Fig. 3. Comparison of observed (filled circles) and calculated (full and dashed lines) intraband $B(M1)/B(E2)$ values for the $\frac{7}{2}^-[\tilde{4}\tilde{0}\tilde{4}]$ band in ^{185}Os. See the text for details.

and all but the $I = 11/2$ limit can be explained by the pseudo-Nilsson calculations with $\chi = 1.0$. The calculations with $\chi = 0.6$ predict much larger ratios, and are consistent with all of the observed data. The Woods-Saxon calculations, like the pseudo-Nilsson, also reproduce these $M1$ data with the exception of the large lower limit for the $I = 11/2$ state. It should be noted that the intraband 129 keV $7/2^- \rightarrow 5/2^-$ transition in the $K^\pi = 3/2^-$ band reported in ref. [9] has not been observed in the current work, where the intensity limit is a factor of 2 lower.

It is interesting to see whether the pseudo-Nilsson model continues to provide a good approximation for higher-K orbitals. In ref. [17], only the $K = 1/2$ and $K = 3/2$ bands were surveyed for the neutron $\tilde{N} = 4$ pseudo-oscillator shell. In the present work, the observation of the $\frac{7}{2}^-[\tilde{4}\tilde{0}\tilde{4}]$ ($\frac{7}{2}^-[503]$) band allows a new high-K regime to be sampled to high spins. The pseudo-Nilsson partner of the $K^\pi = 7/2^-$ band, the $\frac{9}{2}^-[\tilde{4}\tilde{0}\tilde{4}]$ ($\frac{9}{2}^-[505]$) structure, has not been identified experimentally, and thus cannot be properly accounted for in the calculations: however, the predicted branching ratios were found to depend only weakly on the relative energy of the two partner bands. Experimental and calculated intraband $B(M1)/B(E2)$ values for the $K^\pi = 7/2^-$ intraband are shown in fig. 3. The pseudo-Nilsson calculations with $\chi = 1.0$ and 0.6 produce very similar results, differing by less than 20% over the entire spin range. The general trend of the data, but not the absolute magnitude, is well reproduced. The predictions with $\chi = 0.6$ are the more successful of the two, but under-estimate the data by approximately 40%. This may reflect an over-estimate of the quadrupole moment in the calculations. A smaller deformation might be expected for the higher-K band from the behaviour of the Nilsson orbitals, and indeed the experimental moments of inertia of the bands suggest that this is the case. The predictions of the Woods-Saxon calculations closely match the observed data up to spin $I = 17/2$, beyond which, like the pseudo-Nilsson calculations, the model under-predicts the branching ratios.

The calculations discussed above are limited to an axial symmetric potential. Recently, studies of the neighbouring even-even isotopes ^{184}Os [12] and ^{186}Os [14] suggest that while these nuclei have γ-soft shapes at low spins, the nucleus may become polarised by specific multi-quasiparticle excitations at higher spins and take on a triaxial deformation. Likewise, ^{181}Os has been shown to exhibit an axially deformed shape at low spins, but an increasingly γ-soft potential at higher angular momenta [23,24]. However, since the discussion here is limited to the low-lying configurations in ^{185}Os, it is probable that the mean nuclear shape is prolate deformed. Note that the relativistic pseudo-spin symmetry ought to persist independent of whether the potential is spherical, axially or triaxially deformed [25], but the detailed predictions presented here are applicable only for axial deformation.

6 Summary and conclusions

In summary, the low-lying 1-quasiparticle structures of $^{185}_{76}$Os have been studied via a fusion-evaporation reaction induced by carbon-12 ions incident on a ^{176}Yb target. The ground-state $\frac{1}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ 1-quasineutron band has been extended. The unfavoured signature of the $\frac{3}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ structure has also been identified together with higher-spin states in the favoured signature and the $\frac{7}{2}^-[\tilde{4}\tilde{0}\tilde{4}]$ band. These results have been compared with predictions of both pseudo-Nilsson and "normal" Woods-Saxon particle-rotor calculations. The behaviour of transitions associated with the pseudo-Nilsson doublet structure $\frac{1}{2}^-$, $\frac{3}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ is well-reproduced in the pseudo-Nilsson model. The best quantitative agreement with these new data is reached when the Coriolis interactions are not quenched.

In earlier work [26], it seemed that the $M1$ properties of higher-K structures, which have very simple wave functions, were better described in the pseudo-Nilsson scheme than those of low-K bands. The present observation of both low-K and high-K bands in the same nucleus allows for a more stringent assessment of this suggestion. It now appears that the K value is not the critical factor. Rather, in agreement with the conclusions of ref. [17], the general rule is that the pseudo-Nilsson approximation is most appropriate for those orbits that occur at high excitation in the shell of interest where admixtures of the spherical orbit with $j = N+1/2$ ($\nu h_{11/2}$ in the present case) are small in the deformed (Nilsson) wave functions.

The bands built on the $\frac{1}{2}^-$, $\frac{3}{2}^-[\tilde{4}\tilde{1}\tilde{1}]$ orbits in ^{183}W stood out in ref. [17] as excellent examples where the pseudo-Nilsson model description of the electromagnetic properties rivals a conventional Woods-Saxon–based model. The present work shows that this conclusion also applies to these bands in neighbouring nuclei and for spins up to the first band crossing. Thus, aspects of otherwise complex nuclei in the $A = 180$ region can be described successfully by a simplified pseudo-spin model.

The technical staff of the 14UD accelerator are thanked for their support and for the friendly working atmosphere. Dr P.H. Regan is thanked for helpful suggestions and Prof. P.M. Walker is thanked for commenting on the manuscript. The following people are thanked for their help with shifts during the experiment: P.M. Davidson, M. Dasgupta, H. El-Masri, J.C. Hazel and T. Kibédi. This work is supported by the UK EPSRC and by the ANU-EPSRC Agreement.

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