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^{189}Os AND THE U(6/12) SYMMETRY SCHEME

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Abstract This contribution will consider the extension of the U(6/12) symmetry scheme to the region intermediate between the O(6) and SU(3) limits and will compare the predicted level structure with that determined empirically for ^{189}Os.

INTRODUCTION

The extension of the Interacting Boson Model[1] (IBM) description of even-even nuclei to odd-mass nuclei is contained in the Interacting Boson-Fermion Model[2] (IBFM) which considers an odd-mass nucleus in terms of an odd fermion coupled to an even-even core defined within the framework of the IBM. The underlying group structure of the IBFM is of the form $U^B(6)xU^F(m)$ where $U^B(6)$ represents the even-even core and $U^F(m)$ the odd-fermion. The nuclei at the upper end of the N=82-126 neutron shell are well suited to a description of this type. The odd neutrons occupy the $2p_{1/2}$, $2p_{3/2}$ and $1f_{5/2}$ shell model states and this corresponds to an m value of 12. Symmetry schemes corresponding to SU(5), SU(3) and O(6) core symmetries have been deduced[3] for this $U^B(6)xU^F(12)$ framework and comparisons between the level schemes of ^{195}Pt, ref.[4], and ^{185}W, ref.[5], and the O(6) and SU(3) limits respectively suggest that the model

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has some validity. The question we will consider is whether it is possible to propose an interpretation for the nuclei transitional between these two limiting cases.

THE CONSISTENT-Q-FORMALISM IN ODD-A NUCLEI

One possible answer to this problem has been suggested in terms of the recently proposed Consistent-Q-Formalism in Odd-A nuclei (CQFOA)[6] in which the region transitional between the strict SU(3) and O(6) limits is characterized by one parameter χ and the boson number N. This is a direct extension of the consistent-Q-formalism description of even-even nuclei[7].

In the SU(3) chain decomposition of the U(6/12) scheme, the Hamiltonian which can be used to describe the low-lying structure of ^{185}W is given by:

$$H = aC_{2U^{BF}(6)} + bC_{2SU^{BF}(3)} + cC_{2O^{BF}(3)} + dC_{spin^{BF}(3)} , \qquad (1)$$

where a, b, c, d are constants and $C_{2U^{BF}(6)}$ etc. are the Casimir operators of the subgroups in the chain decomposition. The Casimir operator of the $SU^{BF}(3)$ group contains a quadrupole-quadrupole interaction of the form:

$$Q.Q = (Q_B+Q_F).(Q_B+Q_F) , \qquad (2)$$

where

$$Q_B = (s^+\tilde{d}+d^+s)^{(2)} + \frac{\chi}{\sqrt{5}} (\tilde{d}d^+)^{(2)} , \qquad (3)$$

and

$$Q_F = K_\mu^{(2)}(2,0) + K_\mu^{(2)}(0,2) + \frac{\chi}{\sqrt{5}} K_\mu^{(2)}(2,2) . \qquad (4)$$

Q_B represents the boson part of the interaction and Q_F the fermion part. The $K_\mu^{(2)}(L,L')$ refer to the fermion genera-

tors where L and L' denote the pseudo-orbital angular momentum, full details of this are given elsewhere (e.g. ref.[8]). When $\chi=-\sqrt{35/2}$, the strict SU(3) limit is attained and when $\chi=0$ a specific O(6) limit is reached. The Casimirs of the U(6),O(3) and Spin(3) groups contribute only diagonal terms to the Hamiltonian so that for intermediate values of χ, the wavefunctions are specified uniquely by the value of χ and of the boson number N. Then if the E2 operator is defined by:

$$T(E2) = \alpha(Q_B+Q_F) \ , \tag{5}$$

ratios of B(E2) values can be used for a given N to be a measure of χ. Similarly ratios of single particle structure factors for transitions to levels of the same spin can give a measure of χ.

For nuclei near the end of closed shells, the lowest order transfer operator for the pickup reaction is given by:

$$P_j^+ = \zeta_j a_j^+ \ , \tag{6}$$

where ζ_j is an independent parameter. The ratio of (d,t) structure factors for states of the same spin is therefore parameter-free, and figure 1 shows the variation of one such ratio as a function of χ. The K_p=1,2 notation refers to different bands within the anti-symmetric {[N,1]} representation of states. The calculated ratios for the two spin values are identical because each 3/2, 5/2 pair stems from the same pseudo-L level. For a more detailed explanation of this see e.g. ref.[9]. The dashed lines on figure 1 correspond to the weighted mean of the ratio for the 3/2 states [R(3/2)=0.43(6)] and for the 5/2 states [R(5/2)=0.48(7)] in

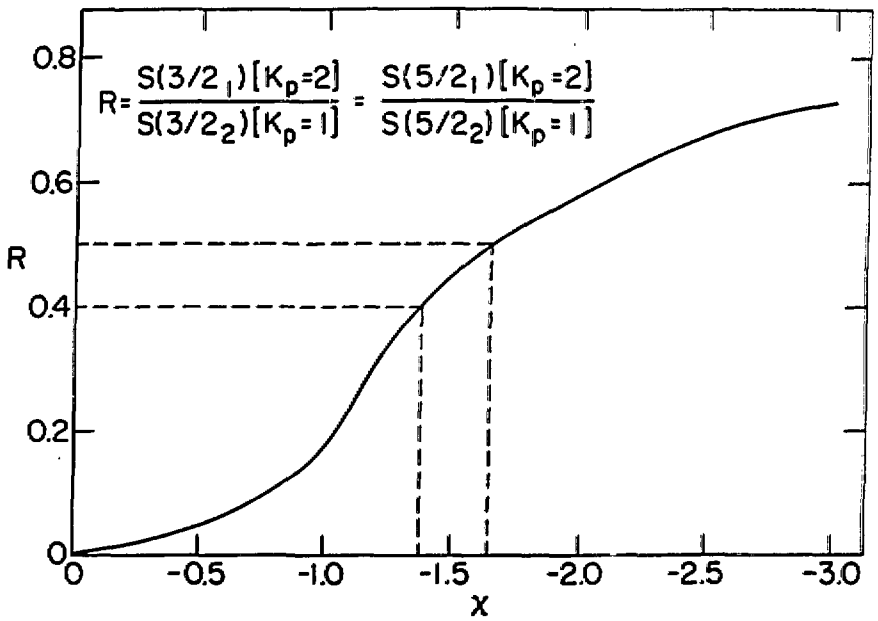

FIGURE 1. The ratio of (d,t) structure factors as a function of χ.

^{189}Os. These two experimental values overlap nicely and define a range of values centered on χ=-1.5. Using this value of χ it is then of interest to make a detailed comparison between the predicted level scheme and that observed for ^{189}Os.

COMPARISON WITH ^{189}Os

In order to make such a comparison meaningful an extensive experimental programme has been carried out to study the structure of ^{189}Os. Initially, experiments were performed at the High Flux Beam Reactor (HFBR) at Brook-

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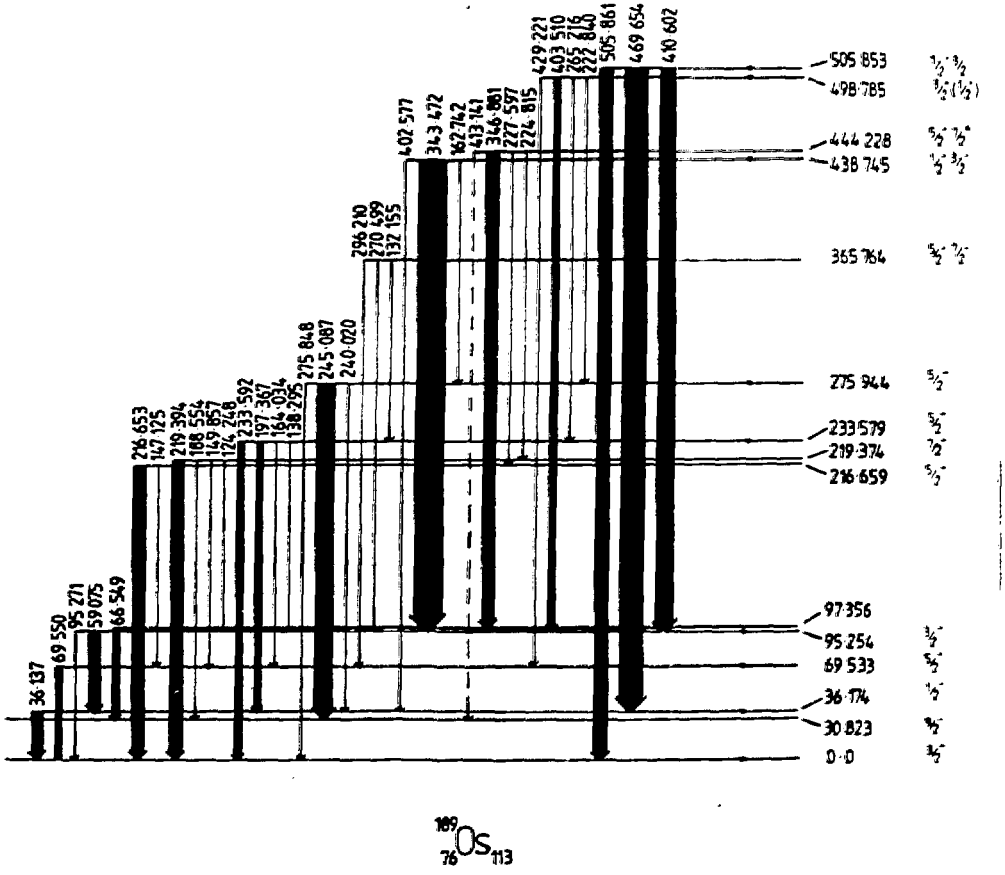

FIGURE 2. The level scheme of ^{189}Os up to 510 keV.

haven National Laboratory with the (n,γ) reaction. Complementary studies involving Coulomb excitation measurements and measurements of the (n,e$^-$) reaction were then carried out at the Manchester Van de Graaff accelerator and at the

Institut Laue-Langevin in Grenoble. At the HFBR, the use of the Average Resonance Capture technique ensured that all $1/2^-$, $3/2^-$ levels have been observed up to an excitation energy determined by the sensitivity of the measurement, in this case ~1.5 MeV. In addition, detailed gamma-gamma coincidence and angular correlation studies were carried out following thermal neutron capture and the results enabled the J^π values of other levels to be determined. Figure 2 shows the level scheme of ^{189}Os up to 510 keV, determined from the measurements performed at Brookhaven. Levels which are marked on the right by a dot are the ones which have been observed in the ARC measurement, where in addition to ALL the $1/2^-$,$3/2^-$ levels, some $1/2^+$, $3/2^+$ and $5/2\pm$ levels were also observed.

The low-lying structure shown in figure 2 is essentially consistent with that previously proposed on the basis of (d,t), (d,p) and (n,γ) studies[10]. One important discrepancy, the full importance of which will become apparent later, involves the 216 keV level which was previously thought to be a $7/2^-$ level and was assigned as the $7/2^-$[503] Nilsson orbit on the basis of the single particle transfer strength observed in the (d,p) and (d,t) reactions[10]. The result of a gamma-gamma angular correlation measurement on the 463-216 keV cascade which originates from the $3/2^-$ level at 679 keV shows that it is less than 0.1% probable that the 216 keV level has $J^\pi = 7/2^-$. Indeed, initial results from the (n,e$^-$) measurement at the ILL show that the 216 keV transition which depopulates this level is a mixed E2/M1 transition with a δ value[11] of $2.46^{+0.27}_{-0.21}$. Since the 216 keV level is not a $1/2^-$,$3/2^-$ level (because it was not observed in the ARC measurement) the only remaining possibility is that it has $J^\pi=5/2^-$. The transfer

strength observed in the (d,t) and (d,p) reactions[10] is inconsistent with this level being assigned as either the $5/2^-$[512] or the $5/2^-$[503] Nilsson state and indeed the detailed Nilsson model calculation discussed in ref.[10] predicts that these states should appear at ~1500 keV excitation energy. The simplest and perhaps only logical conclusion of this dilemma is that the observed single particle strength belongs not to the 216 keV level but to the neighbouring 219 keV level which has a J^π value of $7/2^-$ and would then correspond to the $7/2^-$[503] Nilsson state. This leaves the $5/2^-$ state which since it is not a pure single particle state, must correspond to coupling with some collective excitation in the core.

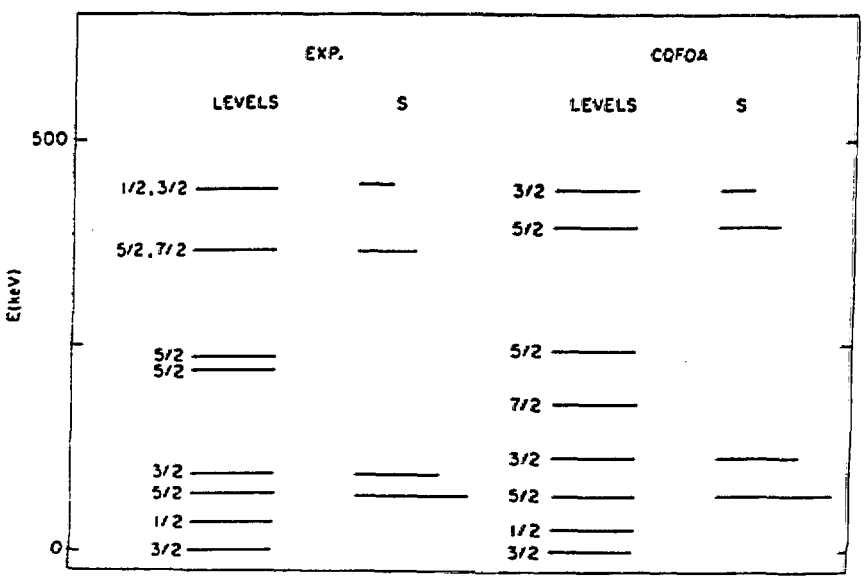

FIGURE 3. Calculated and experimental negative-parity structure in ^{189}Os.

Figure 3 shows the results of a fit to the low-lying level scheme of ^{189}Os using the value of χ=-1.5 deduced from figure 1. On the left of the figure is the experimental energy spectrum up to 475 keV with the level energies being taken from figure 2. The level at 219 keV has been omitted from the figure because it stems from the $h_{9/2}$ shell model state and as such is outside the U(6/12) basis, as are the $9/2^-$ level at 30 keV [which corresponds to the $9/2^-$[505] state] and the $5/2^-$ level at 275 keV (which decays with a measured B(E2) of ~36 s.p.u.[12] to the 30 keV level and has been assigned as the γ-vibrational level built on this state). The levels at 97 and 444 keV have not been included because their J^π values have not yet been uniquely determined, although there is some evidence that they are positive parity states. The single particle structure factors (shown in the column marked S) have been taken from the work of Benson et al.[10]. On the right are shown the level energies and structure factors calculated within the CQFOA using the values of a=-107, b=-15.8, c=18.5 and d=-9 keV in equation 1. Using these values of parameters, no other low spin levels are calculated to lie within the energy range of this figure. It is obvious that in order to be able to make a one-one comparison between empirical and theoretical levels certain assumptions must be made but it is hoped that further analysis will make it possible to distinguish experimentally between the possibilities.

The main problem concerns the 216 keV level which explains why it has been discussed at such length in this contribution. As yet there is no obvious interpretation for this level which since it does not correspond to a pure single particle excitation must involve coupling to excitations in the core. The U(6/12) scheme should automatically

include a more complete core description than is included in the Nilsson model, but it is noticeable that the value of χ used in this study is rather different from that which would be used in a description of the core nucleus ^{190}Os (where the value of χ used would be ~0.6). Of course, a much more stringent test of any theoretical model can be made by considering the B(E2) values and analysis of the Coulomb excitation measurement is still progressing. Nevertheless, the initial comparison between the empirical level scheme of ^{189}Os and that predicted by the CQFOA is encouraging and bodes well for further study. Even if the low-lying levels can be adequately explained there is still the question of the higher lying levels which are more numerous and may yet provide a more severe stumbling block for the symmetry scheme.

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