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Side-bands in ^{170}Yb

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Abstract. The energy spectra of the even-parity ($K^\pi = 2^+, 3^+$) and odd-parity ($K^\pi = 3^-, 4^-$) side-bands in the doubly even nucleus ^{170}Yb are studied in the framework of the microscopic method of variation after angular momentum projection with nucleon number conservation in each projected state. The calculated energy spectra of the ground band and the four side bands in ^{170}Yb are in good agreement with the corresponding experimental results.

Keywords. Energy spectra; side-bands; even-parity; odd-parity.

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1. Introduction

The microscopic formalism of variation after angular momentum projection (VAP) with nucleon number conservation has been developed (Warke and Gunye 1976; Gunye and Warke 1979) and applied to study the yrast states of a number of doubly even nuclei in the rare-earth and transition region (Gunye and Kumar 1980; Kumar and Gunye 1980). This method has also been employed to study the yrast and yrare bands in even-even nuclei after incorporating the band-mixing between the two bands (Moholkar *et al* 1980) and the intrinsic structure and the energy spectra of the ground and excited bands in odd-A nuclei (Moholkar *et al* 1982). The VAP method was also extended to study the bands in doubly odd nuclei (Moholkar *et al* 1983). We apply the VAP method here to study the side bands of either parity in doubly-even nuclei.

In this paper, we report the energy spectra of the four side bands in ^{170}Yb along with the results for the ground band, using the VAP formulation. The side bands in ^{170}Yb are obtained by annihilating two neutrons near the Fermi surface of ^{172}Yb. The theoretical formulation is sketched briefly in §2 and the results are presented and discussed in §3.

2. Theoretical formulation

It is well known that an accurate calculation of the excited states of heavy nuclei from a microscopic many-body theory would require a large configuration space. The computational difficulties of such calculations are reduced by employing a simpler many-body Hamiltonian. We use the quadrupole plus pairing interaction Hamiltonian whose parameters were determined by Kumar and Baranger (1968) from their study of

equilibrium deformation of heavy nuclei.

$$H = \sum_{\alpha} \varepsilon_{\alpha} a_{\alpha}^{\dagger} a_{\alpha} - \frac{1}{2} \chi \sum q_{\alpha\gamma}^{\mu} q_{\delta\beta}^{\mu} a_{\alpha}^{\dagger} a_{\beta}^{\dagger} a_{\delta} a_{\gamma}$$

$$- \frac{1}{2} G \sum (-)^{j_{\alpha} - m_{\alpha} + j_{\gamma} - m_{\gamma}} a_{\alpha}^{\dagger} a_{\bar{\alpha}}^{\dagger} a_{\bar{\gamma}} a_{\gamma}. \tag{1}$$

Here q^{μ} is the quadrupole operator and χ and G are the strengths of the quadrupole and pairing interactions respectively. The subscript α in (1) denotes all the quantum numbers $(n_{\alpha}, l_{\alpha}, j_{\alpha}, m_{\alpha})$ necessary for specification of a spherical single-particle state. The state $\bar{\alpha}$ is connected to state α by a time-reversal operator. The sums in (1) run over the entire configuration space of $N = 4$ and 5 major shells for protons and $N = 5$ and 6 major shells for neutrons.

We take the intrinsic variational wavefunction to be axially symmetric since the nuclei ^{170,172}Yb prefer an axially symmetric equilibrium deformation (Das Gupta and Preston 1963; Gunye *et al* 1964; Kumar and Baranger 1968). The intrinsic wavefunction ϕ_0 of the doubly even nucleus is given by

$$\phi_0 = \prod_i (\mu_i + v_i b_i^{\dagger} b_{\bar{i}}^{\dagger}) |0\rangle, \tag{2}$$

where $b_i^{\dagger}$ is the fermion operator corresponding to the deformed single-particle state i with occupation probability $v_i^2 (= 1 - u_i^2)$. The fermion operator $b_i^{\dagger}$ is obtained from the spherical state operator $a_{\alpha}^{\dagger}$ by the transformation

$$b_i^{\dagger} = \sum_{\alpha} \langle \alpha | C | i \rangle a_{\alpha}^{+}, \tag{3}$$

where C is the transformation matrix. The intrinsic state ϕ_K of the nucleus with A-2 nucleons can be obtained from the intrinsic state ϕ_0 of the nucleus with A nucleons by annihilating two nucleons in the two deformed single-particle states K_1 and K_2. Thus one can construct two states with band quantum numbers $K = K_1 + K_2$ or $K = |K_1 - K_2|$. The projected wavefunction in the JM state of the nucleus with A-2 nucleons is then given by

$$\Psi_{MK}^{J} = N^{J} [P_{MK}^{J} \phi_K + (-)^{J-K} P_{M-K}^{J} \phi_{-K}], \tag{4}$$

where

$$\phi_K = b_{\bar{K}1} b_{\bar{K}2} \phi_0; \quad \phi_{-K} = b_{K1} b_{K2} \phi_0. \tag{5}$$

The normalization constant N^J in (4) is given by

$$N^{J} = 2^{-1/2} [\langle \phi_K | P_{KK}^{J} | \phi_K \rangle + (-)^{J-K} \langle \phi_K | P_{K-K}^{J} | \phi_{-K} \rangle]^{-1/2}. \tag{6}$$

where P_{MK}^{J} in (4) and (6) is the angular momentum projection operator. The energy E_K^J is the expectation value of the Hamiltonian H in (1) in the state Ψ_{MK}^{J} of (4) of the nucleus with A-2 nucleons and is given by

$$E_K^J = \langle \Psi_{MK}^{J} | H | {}_{MK}^{J} \rangle$$

$$= \frac{[\langle \phi_K | H P_{KK}^{J} | \phi_K \rangle + (-)^{J-K} \langle \phi_K | H P_{K-K}^{J} | \phi_{-K} \rangle]}{[\langle \phi_K | P_{KK}^{J} | \phi_K \rangle + (-)^{J-K} \langle \phi_K | P_{K-K}^{J} | \phi_{-K} \rangle]}. \tag{7}$$

Thus one has to evaluate the matrix elements $\langle \phi_K | R | \phi_{\pm K} \rangle$ and $\langle \phi_K | HR | \phi_{\pm K} \rangle$, where R is the usual rotation operator, in order to calculate the energy E_K^J in (7). The

calculation of these matrix elements is obviously quite complicated. To reduce computational complexity, we neglect the relatively insignificant part of the interaction of the nucleons in the K_1 and K_2 orbitals with the rest of the nucleons. One has to use some discretion in this approximation. In the evaluation of $\langle \phi_K | HR | \phi_{\pm K} \rangle$, we have included the exact single-particle energy contributions and the quadrupole interaction contributions of the two nucleons with those in the core. After carrying out the detailed algebra, we obtain the following expressions

$$\langle \phi_K | R | \phi_{\pm K} \rangle = \langle \phi_0 | R | \phi_0 \rangle Y_{K_\mp}, \tag{8}$$

$$\langle \phi_K | HR | \phi_{\pm K} \rangle = \langle \phi_0 | R | \phi_0 \rangle \{ \langle HR \rangle Y_{K_\mp} + Z_{K_\mp} \}, \tag{9}$$

where $\langle \phi_0 | R | \phi_0 \rangle$ and $\langle HR \rangle$ are given by

$$\langle \phi_0 | R | \phi_0 \rangle = (\det W)^{1/2}, \tag{10}$$

$$\langle HR \rangle = 2\sum \varepsilon_{ij} \rho_{ji} - G \sum \sigma_{i\bar{i}} - \frac{1}{2} \chi (Q_0^2 + 2Q_{1-}^2 + 2Q_{2+}^2). \tag{11}$$

The expressions for the generalized matrices ρ and σ, W and the quadrupole term $Q_{\mu\pm}$ appearing in (10) and (11) are derived by Gunye and Warke (1979). The expressions for $Y_{K_\mp}$ and $Z_{K_\mp}$ are obtained as

$$Y_{K-} = \sum_{K_1' K_2'} P_{\bar{K}_1 K_1'} P_{\bar{K}_2 K_2'} \{ \rho_{K_2' \bar{K}_2} \rho_{K_1' \bar{K}_1} - \rho_{K_2' \bar{K}_1} \rho_{K_1' \bar{K}_2} + \sigma_{\bar{K}_2 \bar{K}_1} \sigma_{K_2' K_1'} \}. \tag{12}$$

$$Y_{K+} = \sum_{K_2', K_2'} P_{K_1 K_1'} P_{K_2 K_2'} \{ \rho_{K_2' K_2} \rho_{K_1' K_1} - \rho_{K_2' K_1} \rho_{K_1' K_2} + \sigma_{K_2 K_1} \sigma_{K_2' K_1'} \}.$$

$$Z_{K-} = -(p\rho)_{\bar{K}_1 \bar{K}_1} (P \rho \varepsilon \rho)_{\bar{K}_2 \bar{K}_2} - (P\rho)_{\bar{K}_2 \bar{K}_2} (P \rho \varepsilon \rho)_{\bar{K}_1 \bar{K}_1}.$$

$$Z_{K+} = -(P\rho)_{K_1 \bar{K}_1} (P \rho \varepsilon \rho)_{K_2 \bar{K}_2} - (P\rho)_{K_2 \bar{K}_2} (P \rho \varepsilon \rho)_{K_1 \bar{K}_1}, \tag{13}$$

where

$$P = \tilde{C} \tilde{D}^* C.$$

Here C is the transformation matrix in (3) and D is the rotation matrix. The final expression for the energy E_K^J in the projected state Ψ_{MK}^J in (4) of the nucleus with A-2 nucleons is given by

$$E_K^J = \frac{\int_0^\pi (\det W)^{1/2} \{ \langle HR \rangle y_K^J(\theta) + z_K^J(\theta) \} \sin\theta \, d\theta}{\int_0^\pi (\det W)^{1/2} y_K^J(\theta) \sin\theta \, d\theta}, \tag{14}$$

where

$$y_K^J(\theta) = Y_{K-}(\theta) d_{KK}^J(\theta) + (-)^{J-K} Y_{K+}(\theta) d_{K-K}^J(\theta).$$

$$z_K^J(\theta) = Z_{K-}(\theta) d_{KK}^J(\theta) + (-)^{J-K} Z_{K+}(\theta) d_{K-K}^J(\theta). \tag{15}$$

The energy E^J of the ground band of the even-even nucleus with A nucleons is given by

$$E_0^J = \frac{\int_0^\pi (\det W)^{1/2} \langle HR \rangle d_{00}^J(\theta) \sin\theta \, d\theta}{\int_0^\pi (\det W)^{1/2} d_{00}^J(\theta) \sin\theta \, d\theta} \tag{16}$$

3. Results and Discussion

The nuclear energies of the doubly even nucleus ^{172}Yb are calculated by minimizing E_0^J of (16) and those of ^{170}Yb by minimizing E_K^J of (14) and (15) by varying the deformation (β), pairing gaps (Δ_p, Δ_n) and the chemical potentials (λ_p, λ_n) for each angular momentum state J. The constraint of nucleon number conservation is used to determine the chemical potentials in each projected state. The parameters χ and G of the Hamiltonian in (1) were determined by Kumar and Baranger (1968) by restricting the configuration space to two major shells for each proton and neutron and assuming an inert core of 40 protons and 70 neutrons which necessitates the modification of the calculated energies. The simplest way to incorporate the effect of the neglected core on the excitation energies is by renormalizing the calculated energy spectrum (Gunye and Warke 1979) by introducing a parameter I_c for the moment of inertia of the core. We assume that the moment of inertia of a nucleus in a state J is the sum of the moments of inertia I_c of the core and I_0^J of the outer valence nucleons. The moment of inertia I_0^J depends on J as evident from the calculated energies E_{calc}^J. Thus we get

$$E_{\text{calc}}^J = \frac{\hbar^2 J(J+1)}{2I_0^J}, \tag{17a}$$

for the yrast band of ^{172}Yb and

$$E_{\text{calc}}^J = \frac{\hbar^2}{2I_0^J}[J(J+1) - K(K+1)]. \tag{17b}$$

for K-band of ^{170}Yb. The corrected renormalized energy in the state J is then given by

$$E_{\text{norm}}^J = E_{\text{calc}}^J[1 + (I_c/I_0^J)]^{-1}. \tag{18}$$

We have fixed the value of I_c by renormalizing the energy of the 2^+ yrast state in ^{172}Yb and have used the same value to calculate the different bands in ^{170}Yb.

We have studied the $K^\pi = 0^+$ yrast bands in ^{172}Yb and ^{170}Yb, the two low-lying positive parity side bands ($K^\pi = 2^+, 3^+$) and the two low-lying negative parity side bands ($K^\pi = 3^-, 4^-$) in ^{170}Yb in the framework of VAP formalism outlined in §2. Such microscopic variational calculations in a large configuration space of two major shells each for protons and neutrons are quite involved and very lengthy. Consequently, the band-mixing is not incorporated in this paper.

3.1 *The yrast band in ^{172}Yb and ^{170}Yb*

The calculated renormalized energy E_{norm}^J and the experimental energy E_{expt}^J for each of the angular momentum state J in the yrast bands of ^{172}Yb and ^{170}Yb are shown in tables 1 and 2 respectively. The values of the variational parameters β, Δ_p and Δ_n corresponding to the minimum of energy of each state are also shown in tables 1 and 2. It is seen from the two tabulations that there is no significant variation in proton pairing gap Δ_p with angular momentum. The neutron pairing gap Δ_n, however, first decreases gradually with increasing J and then starts decreasing drastically. The neutron pairing gap vanishes at $J = 14$ in ^{170}Yb and at $J = 12$ in ^{172}Yb and remains zero for all higher angular momentum states. The calculated energies of the ground band are renormalized by employing the value $I_c = 12{\cdot}5\hbar^2/\text{MeV}$ for all the states. This value is determined so as to reproduce the experimental energy of the 2^+ yrast state in ^{172}Yb. It

Table 1. Calculated and experimental energies (in MeV) E^J_{norm} and E^J_{expt} are tabulated for each angular momentum state J in the ground band of ^{172}Yb.

J^π	β	Δ_p	Δ_n	$E^{J^*}_{expt}$	E^J_{norm}
0^+	0·32	0·82	0·63	0·00	0·00
2^+	0·32	0·82	0·63	0·08	0·08
4^+	0·34	0·82	0·63	0·26	0·26
6^+	0·34	0·79	0·57	0·54	0·53
8^+	0·34	0·79	0·40	0·91	0·89
10^+	0·34	0·67	0·23	1·37	1·29
12^+	0·34	0·67	0	1·91	1·72
14^+	0·34	0·67	0	—	2·22
16^+	0·34	0·67	0	—	2·79
18^+	0·34	0·67	0	—	3·42
20^+	0·34	0·67	0	—	4·13

* Greenwood (1975).

Table 2. Calculated and experimental energies (in MeV). E^J_{norm} and E^J_{expt} are tabulated for each angular momentum state J in the ground band of ^{170}Yb.

J^π	β	Δ_p	Δ_n	$E^{J^*}_{expt}$	E^J_{norm}
0^+	0·32	0·84	0·68	0·00	0·00
2^+	0·32	0·84	0·65	0·08	0·08
4^+	0·32	0·84	0·60	0·28	0·26
6^+	0·32	0·84	0·55	0·57	0·55
8^+	0·34	0·81	0·46	0·96	0·92
10^+	0·34	0·78	0·34	1·44	1·34
12^+	0·34	0·75	0·20	1·98	1·84
14^+	0·34	0·72	0	2·58	2·38
16^+	0·34	0·72	0	3·20	2·95
18^+	0·34	0·72	0	3·81	3·52
20^+	0·34	0·72	0	4·44	4·10

* Walker *et al* (1981).

is seen from tables 1 and 2 that the renormalized energies are in fairly good agreement with the corresponding experimental energies.

The structure of the side-bands in the even-even nucleus ^{170}Yb can be understood from the intrinsic state of the nucleus ^{172}Yb. The excited side-bands in ^{170}Yb are constructed by annihilating two neutrons from different orbits near the Fermi surface of neutrons in the intrinsic state of ^{172}Yb. In the range of deformations relevant to ^{170}Yb, the neutron orbits in the vicinity of Fermi surface in ^{172}Yb are characterized by $\Omega_1^\pi = 7/2^+$ predominantly ($\sim 97\%$) from $0i_{13/2}$ state, $\Omega_2^\pi = 1/2^-$ with large admixtures from various single-particle states and $\Omega_3^\pi = 5/2^-$ predominantly ($\sim 88\%$) from $0h_{11/2}$ state. We have considered these three neutron orbits in constructing the low-lying side-bands of both parity in the nucleus ^{170}Yb. By annihilating a neutron from each of the orbits with $\Omega_1 = 7/2^+$ and $\Omega_2 = 1/2^-$ in ^{172}Yb, one obtains the two negative parity bands in ^{170}Yb with band quantum numbers $K_1^\pi = \Omega_1 + \Omega_2 = 4^-$ and $K_2^\pi = |\Omega_1 - \Omega_2| = 3^-$. The higher excited side-bands $K^\pi = 6^-$ and 1^- corresponding to the neutron annihilation from orbits $\Omega_1 = 7/2^+$ and $\Omega_3 = 5/2^-$ are not considered in our present investigations. The low-lying positive parity side-bands are constructed by annihilating a neutron from each of the orbits $\Omega_2^\pi = 1/2^-$ and $\Omega_3^\pi = 5/2^-$. The band quantum number of these positive parity side-bands are $K_3^\pi = \Omega_2 + \Omega_3 = 3^+$ and $K_4^\pi = |\Omega_2 - \Omega_3| = 2^+$. We have performed calculations for all these four experimentally observed (Walker *et al* 1981) side-bands in ^{170}Yb.

3.2 *Negative parity bands* ($K^\pi = 3^-, 4^-$) *of* ^{170}Yb

In the microscopic VAP formalism, the energy of each J state in the band K is obtained by minimizing E^J_K in (14) (β), (Δ_p, Δ_n) and (λ_p, λ_n). The calculated energies in both the $K_1^\pi = 4^-$ and $K_2^\pi = 3^-$ bands are renormalized by employing the same I_c value obtained from the renormalization of the energy of the 2^+ yrast state in ^{172}Yb. The calculated and the corresponding experimental (Walker *et al* 1981) energy spectra are displayed in table 3 for the $K_1^\pi = 4^-$ band and in table 4 for the $K_2^\pi = 3^-$ band. The values of the variational parameters β, Δ_p and Δ_n corresponding to the minimum energy

in each angular momentum state are also shown in tables 3 and 4. It can be seen from tables 3 and 4 that the pairing gaps Δ_p and Δ_n and deformation β change only slightly with J. Moreover, the behaviour of these parameters is almost identical for the two bands. Also there is a good agreement between the calculated and experimental energies in both the negative parity bands. In the $K_2^\pi = 3^-$ band, the $J = 3^-$ and 4^- members of the band are not so far observed. According to our calculations, the energy levels $J = 3^-$ and $J = 4^-$ of this $K_2^\pi = 3^-$ band should occur at 1·48 MeV and 1·56 MeV excitation energies respectively. It should be mentioned here that the calculated energy separation of 220 keV between the $J = 5^-$ state from $K_2^\pi = 3^-$ band and the band-head $J = 4^-$ of the $K_1^\pi = 4^-$ band agrees fairly well with the corresponding energy separation of 400 keV observed experimentally.

3.3 *Positive parity bands* ($K^\pi = 2^+, 3^+$) *of* ^{170}Yb

The calculated energy spectra of the $K_3^\pi = 3^+$ and $K_4^\pi = 2^+$ bands are shown along with the experimental energy spectra (Walker *et al* 1981) in tables 5 and 6 respectively. The values of the variational parameters corresponding to the minimum energy in each angular momentum state are also shown in tables 5 and 6. The calculated energies in both the $K_3^\pi = 3^+$ and $K_4^\pi = 2^+$ bands are renormalized by employing the same $I_c = 12{\cdot}5\hbar^2/\text{MeV}$ value obtained from fitting the energy of 2^+ yrast state in ^{172}Yb. As seen from tables 5 and 6, there is a good agreement between the calculated and experimental energies for almost all the states in both the bands. The band-head of the $K_3^\pi = 3^+$ band is not experimentally observed. Our calculations predict the excitation energy of this $J^\pi = 3^+$ state as 1·30 MeV. It should also be mentioned here that the observed energy separation of 350 keV between the 4^+ state of $K_3^\pi = 3^+$ band and the 2^+ band-head of $K_4^\pi = 2^+$ band is fairly well reproduced (210 keV) by our calculations.

The results obtained in the ground and the four excited bands in ^{170}Yb are

Table 3. Calculated and experimental energies in (MeV). E^J_{norm} and E^J_{expt} are tabulated for each angular momentum state J in the excited band 4^- band of ^{170}Yb. (The energies are with respect to the band head energy of 4^- state).

J^π	β	Δ_p	Δ_n	E^{J*}_{expt}	E^J_{norm}
4^-	0·28	0·92	0·78	0·00	0·00
5^-	0·28	0·92	0·78	0·09	0·10
6^-	0·28	0·92	0·78	0·19	0·21
7^-	0·28	0·92	0·78	0·31	0·35
8^-	0·28	0·92	0·78	0·46	0·51
9^-	0·28	0·92	0·78	0·61	0·68
10^-	0·28	0·92	0·78	0·80	0·88
11^-	0·28	0·92	0·78	0·98	1·08
12^-	0·30	0·87	0·71	1·21	1·31
13^-	0·30	0·87	0·71	1·42	1·55
14^-	0·30	0·87	0·71	1·71	1·80

* Walker *et al* (1981).

Table 4. Calculated and experimental energies (in MeV) E^J_{norm} and E^J_{expt} are tabulated for each angular momentum state J in the excited band (3^-) of ^{170}Yb. The energies are with respect to the energy of 5^- state which is the lowest in the band. The level 3^- and 4^- are not observed.

J^π	β	Δ_p	Δ_n	E^{J*}_{expt}	E^J_{norm}
3^-	0·28	0·92	0·78	—	−0·18
4^-	0·28	0·92	0·78	—	−0·10
5^-	0·28	0·92	0·78	0·00	0·00
6^-	0·28	0·92	0·78	0·10	0·11
7^-	0·28	0·92	0·78	0·24	0·26
8^-	0·28	0·92	0·78	0·38	0·41
9^-	0·28	0·92	0·78	0·56	0·58
10^-	0·28	0·92	0·78	0·73	0·78
11^-	0·30	0·87	0·71	0·94	0·99
12^-	0·30	0·87	0·71	1·16	1·21
13^-	0·30	0·87	0·71	1·39	1·44

* Walker *et al* (1981).

Table 5. Calculated and experimental energies (in MeV) E^J_{norm} and E^J_{expt} are tabulated for each angular momentum state J in the excited band (3^+) of ^{170}Yb. The energies are with respect to the 4^+ state in the band as the band head 3^+ state is not experimentally observed.

J^π	β	Δ_p	Δ_n	E^{J*}_{expt}	E^J_{norm}
3^+	0·26	0·97	0·86	—	−0·10
4^+	0·26	0·97	0·86	0·00	0·00
5^+	0·26	0·97	0·86	0·12	0·14
6^+	0·26	0·97	0·86	0·26	0·30
7^+	0·26	0·97	0·86	0·43	0·49
8^+	0·28	0·92	0·78	0·60	0·70
9^+	0·28	0·92	0·78	—	0·96
10^+	0·28	0·92	0·78	1·04	1·20
11^+	0·28	0·92	0·78	—	1·49
12^+	0·28	0·92	0·78	—	1·81
13^+	0·28	0·92	0·78	—	2·13

* Walker *et al* (1981).

Table 6. Calculated and experimental energies (in MeV) E^J_{norm} and E^J_{expt} are tabulated for each angular momentum state J in the excited band (2^+) of ^{170}Yb. The energies are with respect to the band head energy of the 2^+ state.

J^π	β	Δ_p	Δ_n	E^{J*}_{expt}	E^J_{norm}
2^+	0·26	0·97	0·86	0·00	0·00
3^+	0·26	0·97	0·86	0·08	0·08
4^+	0·26	0·97	0·86	0·18	0·20
5^+	0·26	0·97	0·86	0·31	0·34
6^+	0·28	0·92	0·78	0·46	0·50
7^+	0·28	0·92	0·78	0·63	0·70
8^+	0·28	0·92	0·78	0·81	0·89
9^+	0·28	0·92	0·78	1·07	1·16
10^+	0·28	0·92	0·78	1·23	1·38
12^+	0·28	0·92	0·78	1·68	1·72
14^+	0·28	0·92	0·78	2·16	1·97

* Walker *et al* (1981).

summarized in figures 1 to 6. The calculated and experimental band-head positions of the $K = 0^+, 2^+, 3^+, 3^-$ and 4^- bands are displayed in figure 1. In the case where the band-head is not experimentally located, the next excited state in that band is compared. The calculated I (moment of inertia) *vs* ω^2 (square of angular velocity) curves are compared with the corresponding experimental curves for the ground $K = 0^+$ band and the excited $K = 2^+, 3^+, 3^-$ and 4^- bands in figures 2 to 6. It is seen from figure 2 that the observed S-shaped I *vs* ω^2 curve is well reproduced by our microscopic calculations. The observed I *vs* ω^2 curves for all the four excited bands have a saw-toothed structure. The present microscopic calculations reproduce this behaviour reasonably well in all the excited bands in ^{170}Yb.

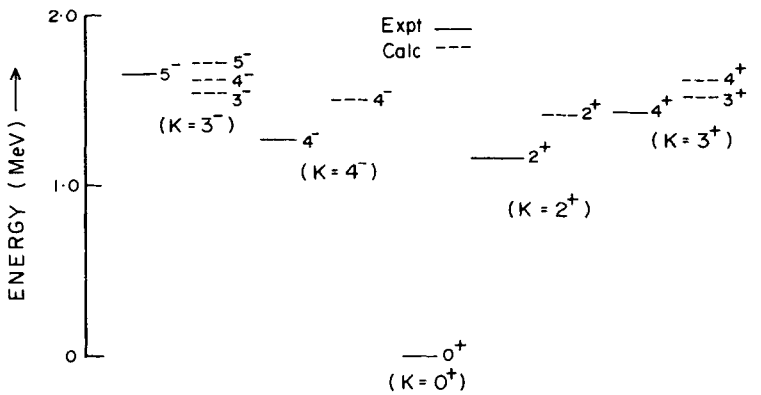

Figure 1. Calculated and experimental band-head positions of the $K = 0^+, 2^+, 3^+, 3^-$ and 4^- bands.

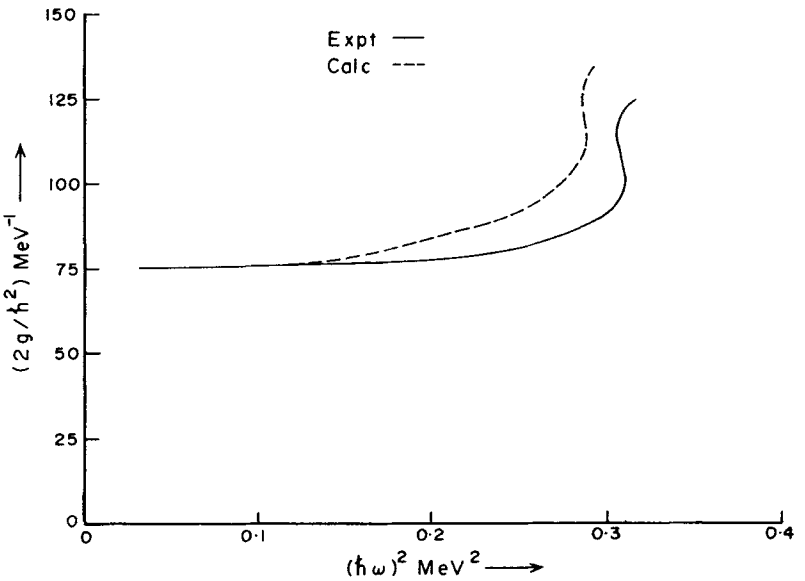

Figure 2. Calculated I *vs* ω^2 curve compared with the corresponding experimental curve for the ground band in ^{170}Yb.

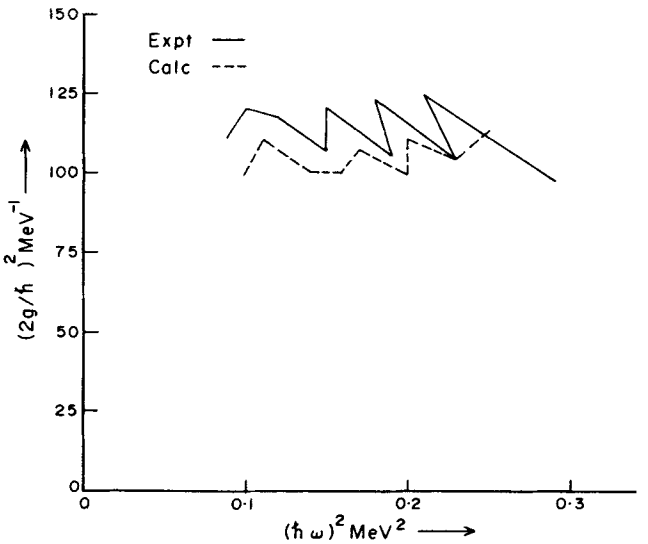

Figure 3. Same as in figure 2 for the $K = 4^-$ band in ^{170}Yb.

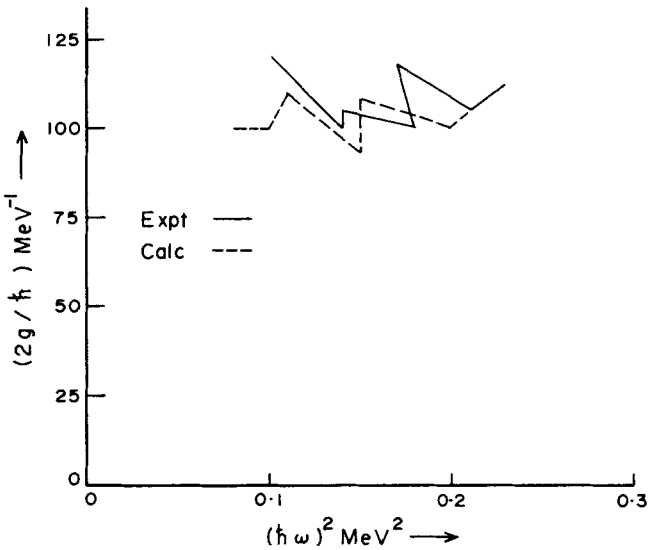

Figure 4. Same as in figure 2 for the $K = 3^-$ band in ^{170}Yb.

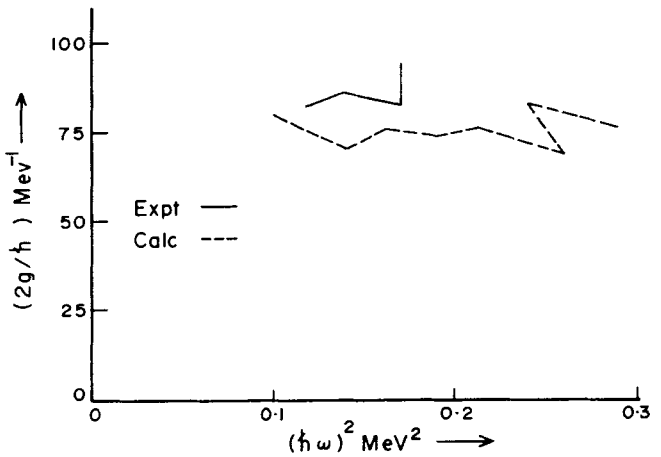

Figure 5. Same as in figure 2 for the $K = 3^+$ band in ^{170}Yb.

4. Conclusions

The microscopic formalism of variation after projection of angular momentum with nucleon number conservation in each projected state is extended to study the low-lying side-bands in the doubly even nucleus ^{170}Yb. The calculations are performed in a large configuration space of two major shells each for the valence protons and neutrons outside an inert core of 40 protons and 70 neutrons. A nuclear Hamiltonian with quadrupole plus pairing interactions is employed in the calculations. The excited side-

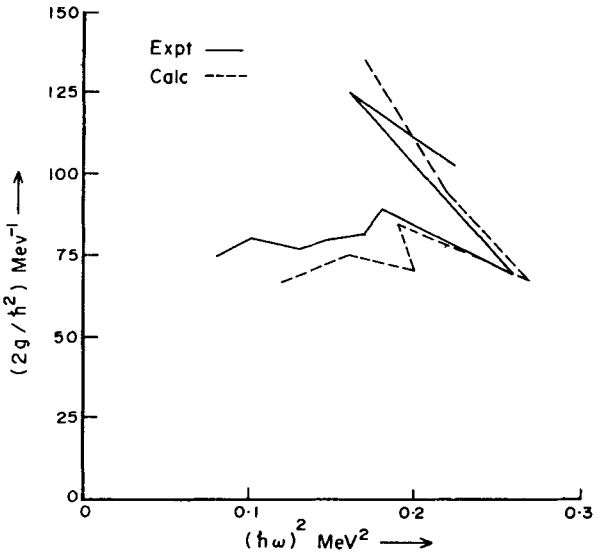

Figure 6. Same as in figure 2 for the $K = 2^+$ band in ^{170}Yb.

bands in ^{170}Yb are constructed by annihilating two neutrons from different orbits near the Fermi level of neutrons in the intrinsic state of ^{172}Yb. It is gratifying to note that the same value ($I_c = 12{\cdot}5\hbar^2$/MeV) of the moment of inertia of the core, gives a good agreement between the calculated and the corresponding experimental energies of all the states in the yrast and the excited side-bands of both parities.

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