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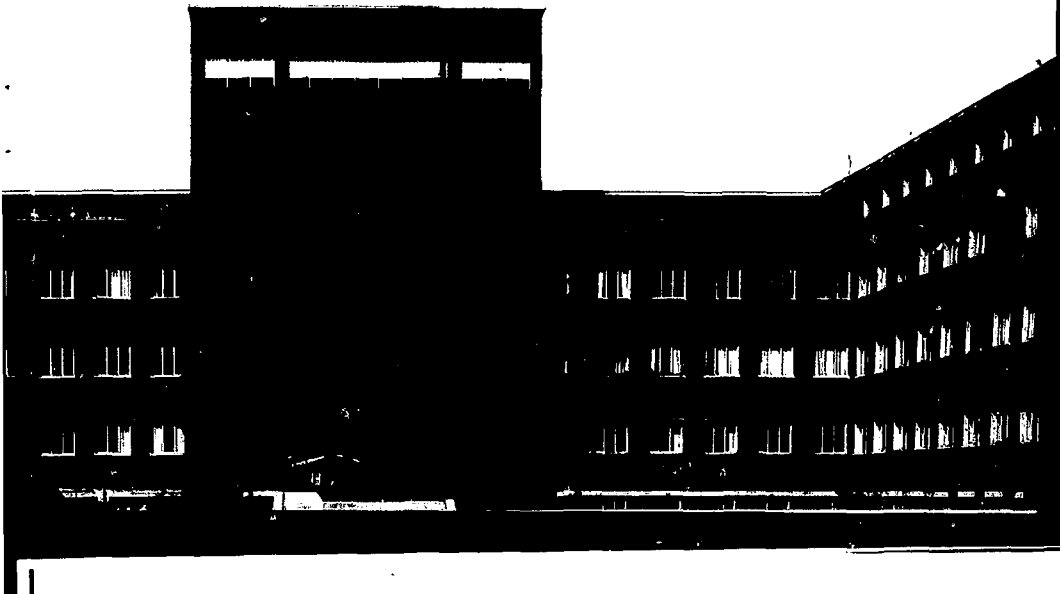

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Abstract:

States in ^{161}Dy have been populated using the inelastic (τ, τ') reaction. Strong particle–groups in the 0.9 MeV excitation region are interpreted to arise from a coupling of an odd particle in the [642]5/2^+ Nilsson orbital to a γ–vibration of the even core. The 1/2^+ and 3/2^+ members of the antialigned particle–vibration sequence are found to interact with states from the $N = 4$ and $N = 6$ oscillator shell, thus modifying previous conclusions on the $\Delta N = 2$ coupling. The particle-vibration states are discussed within a particle–core model.

NUCLEAR REACTION $^{161}Dy(\tau, \tau')$, $E_\tau = 32$ MeV; measured $\sigma(E)$, E_γ, I_γ, τ–γ coin. ^{161}Dy deduced levels, particle–core model calculations. *Si* and *Ge* counters, enriched target.

1 Introduction.

The $5/2^+$ ground state of ^{161}Dy is known[1]) to be well described by the deformation–aligned strong coupling model, in terms of an intrinsic $[642]5/2^+$ Nilsson orbital which originates from the spherical $i_{13/2}$ high–spin orbital. The even-even neighbouring nuclei $^{160,162}Dy$ have well known low–lying states referred to as γ–bands. This study reports on states in ^{161}Dy which we suggest arise from the same collective behaviour.

In recent years a main focus has been on odd–A transitional nuclei, partly to explore effects of the particle–core coupling including Pauli blocking, and partly to shed light on the collectivity and symmetry of the neighbouring even–even core nuclei. Various experimental tools have been employed, including particle transfer reactions[2]). For the most prominent level sequences, those dominated by parentage on the lowest yrast states of the core nuclei, energy spectra and spectroscopic amplitudes are less sensitive to the underlying core–model assumptions than hoped for. States with leading parentage on more complicated core states have been hard to explore; in transfer they involve multi–step processes with small relative cross sections. Thus, the γ–vibration based states reported in this study are of more general interest as a basis for studying current particle–core coupling models in the limit of a well deformed average field. The γ–vibrations in the core nuclei also seem to have substantial anharmonicity[3]).

In the present work we have measured scattered τ particles from $^{161}Dy(\tau,\tau')$ inelastic scattering in coincidence with γ–rays. Information from the observed γ–decay branches was combined with available data from other reaction processes for assignments of spins and parities.

2 Experimental method and results.

The experiment was carried out using a 32 MeV τ beam from the Scanditronix MC 35 cyclotron at the University of Oslo. The target was a self–supporting metallic dysprosium foil of thickness $2mg/cm^2$ enriched to 92% in ^{161}Dy.

Charged ejectiles from the reactions were detected and identified in four particle telescopes positioned at 40° with respect to the beam direction. Each of the telescopes consisted of a front and an end Si counter with thicknesses of 150 μm and 3000 μm, respectively. The telescopes were placed as close to the target as possible ($\approx 4cm$), giving a total solid angle of 250 msr. The resulting particle energy resolution (FWHM) was 300 keV.

The coincident γ–radiation was measured with four Ge counters, each with an energy resolution of 2.2 keV and with an efficiency of 20%. The events were stored on magnetic tapes and analyzed off–line. Background due to random coincidences was subtracted in the sorting procedure. More details on the experimental set–up are given elsewhere[4]).

In *fig.* 1 we show the spectrum of inelastically scattered τ-particles recorded in coincidence with γ-rays detected in the *Ge* detectors. The spectrum is characterized by a strong peak with an excitation energy of 0.9 MeV. We associate this structure with the presence of quadrupole and octupole vibrational modes and it will be referred to as the vibration-peak.

The origin of the small peak around $E_x = 2.5$ MeV is uncertain. It could be due to a more composite collective excitation or to the high level density at the beginning of the three quasiparticle regime. The drop in yield around $E_x =$ 6.6 MeV results from the evaporation of a neutron, which is the dominating process above the neutron binding energy of $B_n = 6.45$ MeV. The ^{160}Dy isotope is then populated with low excitation energy decaying with a correspondingly low γ-ray multiplicity. We also recognize a general decrease in the yield as a function of excitation energy. Taking into account the γ-ray multiplicity dependence of the spectrum, this reduction is even more pronounced in the single particle cross section.

E_γ keV	I_γ ᵃ)	E_x MeV	E_γ keV	I_γ ᵃ)	E_x MeV
417.9 (2)	8 (2)	0.47 (9)	686.9 (1)	58 (6)	0.70 (4)
475.5 (2)	13 (2)	0.48 (8)	699.6 (1)	75 (10)	0.72 (3)
517.7 (3)	27 (6)	0.70 (5)	730.6 (3)	29 (6)	0.74 (5)
532.9 (3)	17 (4)	0.64 (8)	756.6 (1)	100 (10)	0.80 (3)
550.6 (2)	25 (4)	0.48 (5)	772.0 (1)	79 (8)	0.74 (3)
566.3 (1)	54 (10)	0.68 (4)	781.0 (3)	33 (6)	0.89 (5)
587.8 (2)	31 (6)	0.76 (5)	798.6 (1)	104 (15)	0.89 (3)
599.1 (2)	31 (6)	0.72 (5)	800.4 (5)	100 (15)	0.81 (4)
607.5 (2)	73 (8)	0.69 (4)	855.2 (1)	154 (11)	0.90 (3)
624.6 (1)	44 (8)	0.69 (5)	899.0 (1)	79 (8)	0.89 (3)
656.4 (2)	40 (6)	0.68 (5)	981.7 (2)	42 (6)	1.03 (5)
669.1 (2)	79 (10)	0.79 (3)	1005.8 (2)	29 (4)	1.05 (6)
679.4 (9)	12 (4)	0.62 (7)	1026.3 (3)	21 (4)	1.03 (6)
			1045.3 (5)	8 (3)	1.18 (8)

ᵃ) *Normalized to 100 for the 756.6 keV γ-line*

Table 1: Gamma-ray transitions from $E_x = 0.4 - 1.2$ MeV.

The present work is concerned with the structure and decay properties of the pronounced vibration-peak. It consists of several particle groups. This becomes evident by studying the γ-ray *Ge* spectra obtained with gates on various parts of the vibration-peak. In *fig.* 2 it is shown that different groups of γ-lines are connected to different parts of the peak. For the determination of the excitation energies gates have been put on the γ-lines (with proper background subtraction) and centroids of the resulting τ peaks have been evaluated. The corresponding excitation energies are listed in *table* 1 together with the γ–ray energies and intensities.

The upper part of *fig.* 3 (marked (a)) shows a blow–up plot of the vibration-peak in *fig.* 1. Part (b) presents a spectrum constructed from *table* 1 as follows: For each excitation energy E_x the total γ–ray intensity found, $\sum I_\gamma$, is plotted. The spectrum is tentative since weak γ–lines which have not been accounted for could add up to a significant particle peak.

To assign spins and parities a comparison was made with information from the complementary studies (d,d') [5]), (d,t), (d,p) and (n,γ) [6–8]). A spectrum ($\Theta = 90°$) from the 12 MeV deuteron inelastic scattering on ^{161}Dy, studied with a high resolution magnetic spectrograph [5]), is shown in the lower part (d) of *fig.* 3. There is a striking resemblance between this spectrum and the one of part (b) of the present work. This is consistent with the results of DWBA calculations using the DWUCK code [9]). It is found that the ratio of the cross sections in (τ,τ') at 40° and 32 MeV and (d,d') at 90° and 12 MeV are 5.7 and 5.5 for angular momentum transfer $\lambda = 2$ and 3, respectively. The γ–vibration falls a few hundred keV below the octupole vibration in the core nuclei. We have correspondingly assumed the states discussed below to arise from the quadrupole vibration.

A comparison between part (b) and (d) of *fig.* 3 resulted in the identification of 10 levels. They are plotted in part (c) with accurate excitation energies deduced from the γ–ray *Ge* spectra. A partial decay scheme is presented in *fig.* 4.

In the strong coupling model the γ–vibration adds an angular momentum $K_\gamma = 2$ either aligned or antialigned with the particle projection $K_o = 5/2$ along the symmetry axis. This gives rise to two excited band structures [10]), the aligned with band head $K_{\uparrow\uparrow} = K_o + K_\gamma = 9/2$ and the antialigned with $K_{\uparrow\downarrow} = K_o - K_\gamma = 1/2$. The spins of the sequences go as $I = |K|, |K|+1, |K|+2, \ldots$.

For a harmonic γ–vibration the band–head energies are given relative to the yrast band–heads ($5/2^+_{g.s.}$) by

$$\left\{ \begin{array}{c} E^*_{\uparrow\uparrow} \\ E^*_{\uparrow\downarrow} \end{array} \right\} = \left\{ \begin{array}{c} E_{\uparrow\uparrow} \\ E_{\uparrow\downarrow} \end{array} \right\} - E_{K_o} = \left\{ \begin{array}{c} E_{K_\gamma} + 2(2K_o+1)A \\ E_{K_\gamma} - 2(2K_o+1)A \end{array} \right\} \qquad (1)$$

where $A = \hbar^2/2J$ is an appropriate inertial parameter and E_γ the excitation energy of 2^+_γ in the core system. The energy difference between the band heads is consequently $\Delta E(\uparrow\uparrow,\uparrow\downarrow) = 4(2K_o+1)A$. For an estimate we choose $A = 14$ keV, based on an average between the 2^+_γ energies of $^{160,162}Dy$, respectively 87 keV and 81 keV. This gives an energy splitting $\Delta E(\uparrow\uparrow,\uparrow\downarrow) = 336$ keV. For E_{K_γ} we take the average between the observed 2^+_γ energies of $^{160,162}Dy$, respectively 966 keV and 888 keV, giving $E_{K_\gamma} = 927$ keV.

The state which we assign as the $I^\pi = 9/2^+$ band head of the aligned structure corresponds to the intense particle group located at $E_x = 899$ keV i. e. somewhat below the simple model estimate of $E^*_{\uparrow\uparrow} = 1095$ keV.

The state is neither observed in the (d,t) nor in the (d,p) reactions[5]) indicating negligible interaction with other single particle orbitals. Furthermore, the state has a significant γ–decay branch to the high spin $9/2^+$ member of the ground band.Thus we conclude that it is the $I, K^\pi = 9/2, 9/2^+$ aligned state.

Our simple model estimate predicts likewise the anti–aligned band head $I^\pi = 1/2^+$ to be at $E^*_{\uparrow\downarrow} = 759$ keV, i. e. a band head splitting of 336 keV. The experimental candidates for the $I = 1/2$ and $3/2$ members of the $K_{\uparrow\downarrow} = 1/2$ antialigned intrinsic structure are fragmented by neighbouring single particle states. The $1/2^+$ (607.5 keV) and $1/2^+$ (772.0 keV) states have been previously assigned according to $l = 0$ angular distributions observed in (d,t) reactions[5,8]). These states are interpreted as a mixture of the $[400]1/2^+$ and the $[660]1/2^+$ orbitals. However, their inelastic scattering cross sections indicate that they interact also with the $I, K^\pi = 1/2, 1/2^+$ antialigned state. This third $1/2^+$ state gives probably rise to the 699.6 keV level having γ–decay and (d,d') angular distribution similar to the $1/2^+$(607.5 keV) level[5]).

The two lowest $3/2^+$ states of *fig.* 4 are known from (d,t) reactions to be based on the $[402]3/2^+$ and $[651]3/2^+$ orbitals[6,8]). Their weak (d,d') cross–sections[5]) indicate weak interactions with the $I, K^\pi = 3/2, 1/2^+$ state. We suggest that this state corresponds to the strong inelastic particle group at $E_x = 800.5$ keV. The observed γ–decay branches are consistent with this interpretation.

The last strong particle group not assigned is located at 730.7 keV. It decays to $5/2^+$, $7/2^+$, $3/2^-$, $5/2^-$ and $7/2^-$ states. Assuming positive parity, we are left with an $I = 5/2$ assignment. This suggested $I, K^\pi = 5/2, 1/2^+$ state is not found to interact with other states.

The $I, K^\pi = 7/2, 1/2^+$ and $9/2, 1/2^+$ band members could not be identified from our data. This has theoretical support within the strong coupling model which predicts[11]) that the relative strength distribution for direct quadrupole excitation from the ground state to the members of an excited band is governed by the square of the Clebsch–Gordan coefficient

$$< I_o = K_o K_o\, \lambda = 2\, 2\, | I\, K > = < 5/2\, 5/2\, 2\, -2 | \, I\, 1/2 > . \tag{2}$$

This gives intensities of .33, .38, .21, .06 and .01 for spin I = 1/2, 3/2, 5/2, 7/2 and 9/2, respectively. It is satisfactory to notice that the cross sections observed at 90° in the (d,d') reaction[5]) for the assigned 1/2, 3/2 and 5/2 levels are 82, 96 and $41\mu b/sr$, consistent with the rule above. Thus, our assignements have been guided by the strong coupling model. Deviations from this simple picture were, however, found to be present,such as the experimental value $E^*_{\uparrow\uparrow}$ beeing less than E_{K_γ} instead of somewhat larger. This problem is further discussed in sect. 4.

3 Mixing with other states. The $\Delta N = 2$ coupling.

For making comparison with theoretical results the unperturbed energy positions of the $I^\pi = 1/2^+$ and $3/2^+$ members of the $K^\pi = 1/2^+$ antialigned band need to be unfolded from their mixture with the deformed orbitals alluded to above. Transfer data indicates that these orbitals call for a substantial $\Delta N = 2$, i. e. main oscillator quantum number mixing. The leading order $\Delta N = 2$ mixing induces for $I^\pi = 1/2^+$ a linear combination of the $[400]1/2^+$ and $[660]1/2^+$ Nilsson orbits while the orbitals $[402]3/2^+$ and $[651]3/2^+$ are mixed for $I^\pi = 3/2^+$.

Previously, an explicit coupling matrix has been constructed based on the $N = 4$ and $N = 6$ Nilsson orbits only, so as to give admixed states with acceptable energy positions as well as mixing coefficients leading to spectroscopic factors in reasonable agreement with transfer data[4,8]). This procedure is in the following extended to a three–state mixture by including the antialigned band of vibrational nature found in the present work.

The full Hamiltonian was chosen to have the form

$$\mathbf{H} = \mathbf{H_o} + \mathbf{V} = \begin{pmatrix} \varepsilon_1^o & 0 & 0 \\ 0 & \varepsilon_2^o & 0 \\ 0 & 0 & \varepsilon_3^o \end{pmatrix} + v \begin{pmatrix} 0 & 1 & \rho \\ 1 & 0 & \rho \\ \rho & \rho & 0 \end{pmatrix}, \tag{3}$$

assuming a simple interaction matrix. The unperturbed energies ε_j^o, $j = 1, 2, 3$ correspond to a sequence of states $[400]1/2^+$, $[600]1/2^+$ and $(\gamma 1/2, 1/2^+)$ for $I^\pi = 1/2^+$ and $[402]3/2^+$, $[651]3/2^+$ and $(\gamma 1/2, 3/2^+)$ for $I = 3/2^+$. The eigenvalue problem reads

$$\mathbf{H} \cdot \mathbf{\Phi_i} = \varepsilon_i \mathbf{\Phi_i}, \tag{4}$$

with normalized solutions $\mathbf{\Phi_i} = (C_j^i)$ represented in the unperturbed basis.

Previous two–state $\Delta N = 2$ analysis gave a coupling strength $v \approx 60$ keV. In the present case the method of trial and error resulted in a coupling matrix with $v = 65$ keV, $v\rho = 30$ keV, which simultaniously gave a satisfactory fit to the observed energies and spectroscopic data. The energy results are listed in *table* 2 together with the mixing coefficients.

Unperturbed			Perturbed				
j	Config.	ε_j^o keV	i	ε_i keV	Amplitude C_1^i	C_2^i	C_3^i
1	$[400]1/2^+$	675	1	612	.72	.53	-.45
2	$[660]1/2^+$	680	2	779	-.69	.54	-.48
3	$(K_o - K_\gamma)$	730	3	693	-.01	.65	.76
1	$[402]3/2^+$	600	1	561	.87	.43	.26
2	$[651]3/2^+$	670	2	688	-.50	.79	.36
3	$(K_o - K_\gamma)$	770	3	791	-.05	-.45	.89

Table 2: Results for three state coupling calculation.

From the mixing coefficients C_j^i, spectroscopic amplitudes for the final states $i = 1, 2$ and 3 are derived in standard way. In *fig.* 5 and 6 we show that the experimental data are surprisingly well described by our perturbed wave functions. The calculations indicate that the vibrational component in the $I^\pi = 1/2^+$ states (see *fig.* 5) is heavily fragmented. For the $3/2^+$ states the unperturbed vibrational state is more isolated in energy and its character is retained in the mixing procedure. The (d,t) strength displayed in *fig.* 6 confirmes that the $I^\pi = 1/2^+$ states are strongly mixed. In particular, the calculation reveals a destructive interference which cancels the $N = 4$ component in the $K_o - K_\gamma$ states, consistent with a vanishing (d, t) cross section[6]) at $E_x = 699.5$ keV.

The introduction of a third interacting state in the $\Delta N = 2$ coupling modifies previous estimates. In the two–state mixing calculation of Grotdal et al.[6]) the energy spacing $(\Delta\epsilon)$ of the unperturbed $N = 4$ and 6 states was estimated to be 2.5 keV $(1/2^+)$ and 86 keV $(3/2^+)$. The corresponding values in the three–state mixing calculation are 5 keV $(1/2^+)$ and 70 keV $(3/2^+)$. Furthermore, the old approach[6]) gave $\Delta N = 2$ matrix elements (v) of 83 keV $(1/2^+)$ and 47 keV $(3/2^+)$.

The $[660]1/2^+$ Nilsson orbital plays a crucial role for the rotational states in the rare earth nuclei. The Coriolis coupling to this orbital is responsible for the alignment of the angular momentum along the rotational axis. In *table* 2 we find that the $[660]1/2^+$ orbital is fragmented over three states. The 772.0 keV level, which we assign to the $[660]1/2^+$ orbital (see *fig.* 4), contains approximately equal components of the $[400]1/2^+$ and $(K_o - K_\gamma)1/2^+$ structures. This admixture of low–j components will reduce the alignement effect at low spin. Fragmentation of the similar type could explain the necessity to attenuate the Coriolis interaction in the *Particle-Rotor Model* description for several rotational bands in this region. However, we do not believe that such a mechanism is the full explanation of the so–called Coriolis attenuation problem.

In *fig.* 7 we exhibit the observed particle–vibration states (left part) together with the results (middle part) obtained assuming that the interaction to the $N = 4$ and 6 states has been removed. The excitation energies of the $5/2^+$ and $9/2^+$ states remain unchanged. The deduced unperturbed vibrational states have a band–head separation of 169 keV, i. e. substantially smaller than the strong–coupling harmonic vibration estimate given above.

4 A Nuclear Model discussion.

Our discussion has so far referred to a strong coupling rotation-vibration theory[10]), formulated in an intrinsic frame. A harmonic treatment of the γ–vibration turned out to have substantial shortcommings when faced with our data. Thus one has to go beyond this approximation. Furthermore, calculations[3]) of the core nuclei within the Dynamic Deformation theory[12]) gave r.m.s. values $< \gamma^2 >^{1/2}$ of the γ vibration of 17° and 13° respectively for $^{160,162}Dy$. A situation is suggested similar to the one encountered in ^{168}Er with substantial anharmonicities, analyzed in detail in ref.[13,14]).

We leave a further detailed exploration along these lines to a future study. Here we limit our discussion to a few preliminary calculations within an alternative theoretical framework, formulated in the laboratory frame; the Quasiparticle–Core Coupling Model of Dõnau and Frauendorf. For a detailed description of this approach we refer to ref[15,16]). This formulation allow for a variety of core possibilities, ranging from vibrations around a spherical shape to permanent deformations. The present data provides an interesting possibility to test this approach in a well deformed region.

R_g^π	Core Energy (keV) g–Band[a])	R_γ^π	Core Energy (keV) γ-Band[b])
0^+	0	2^+	927
2^+	87	3^+	1006
4^+	282	4^+	1109
6^+	581	5^+	1235
8^+	967	6^+	1377
10^+	1408	7^+	1553
12^+	1957	8^+	1751
14^+	2634	9^+	1751
16^+	3412	10^+	2238
18^+	4290	11^+	2500
20^+	5268		

[a])The excitation energies from $I^\pi = 14^+$ are estimated by the rotation model assupmtion $I(I+1)$.

[b])The excitation energies from $I^\pi = 7^+$ are estimated by the rotation model assumption $I(I+1)$.

Table 3: Experimental core energies for the calculation in the Quasiparticle–Core Coupling Model

In the present calculation a single–particle valence space $\{a = n_a l_a j_a\}$ consisting of the orbitals $\{1i_{13/2}, 2g_{9/2}\}$ was employed with a level separation of 5.4 MeV. An initial calculation was carried out in order to reproduce the ground state band in ^{161}Dy. The core space included the 11 first yrast states $R^\pi = 0^+, 2^+, \cdots, 20^+$, the same set for the lower and upper core and with average experimental energies taken from $^{160,162}Dy$. These are found in *table* 3. The coupling matrix elements between the core states were taken from the rigid rotor model. An attenuation factor $\{U(1)V(2) + U(2)V(1)\}^\alpha$, U(V) beeing standard orbital occupation amplitudes, with $\alpha = 9$ was required to obtain a reasonable reproduction of the experimental "[642]5/2^{+}": $5/2^+, 7/2^+, \cdots$ ground state sequence. The pairing gap was taken from the experimental odd–even mass difference to be $\Delta = 872$ keV and the Fermi level was chosen as $\lambda = -2.1$ MeV below the $1i_{13/2}$ level (set at 0 MeV). The

I_g^π	g–band energies		I_γ^π	γ–band energies	
	Exp. keV	Theor. keV		Exp. keV	Theor. keV
$5/2^+$	0	0	$1/2^+$	0 (730)	0 (844)
$7/2^+$	44	50	$3/2^+$	40	26
$9/2^+$	100	90	$5/2^+$	1	61
$11/2^+$	184	198	$7/2^+$		112
$13/2^+$	267	216	$9/2^+$		20
$15/2^+$	407	436	$9/2^+$	169	174

Table 4: Experimental and calculated energies in ^{161}Dy

results are contained in *table* 4. Next, a similar calculation was carried out for a particle coupled to the γ–band of the core with in–band coupling matrix elements only, also taken from the rigid rotor model. Again the experimental core states are given in *table* 3 and the calculated states for ^{161}Dy are found in *table* 4.

Compared to the simple harmonic γ–vibration analysis in sect. 2 our present result is a clear improvement. The energy separation between the $K_{\uparrow\uparrow} = 9/2$ and $K_{\uparrow\downarrow} = 1/2$ band heads which from our experiments is estimated to 169 keV is well reproduced. However, the spin sequence is not fully reproduced.

In conclusion, our theoretical model analysis supports the interpretation of the new states as γ–vibrations above the ground state of ^{161}Dy.

5 Conclusion

States interpreted as γ–vibrations built on the [642]5/2$^+$ ground state in ^{161}Dy have been populated in the inelastic (τ, τ') reaction. The vibration–coupled states are classified according to their angular momentum projections on the nuclear symmetry axis: (*i*) the aligned structure with $K^\pi = 9/2^+$ and (*ii*) the antialigned structure with $K^\pi = 1/2^+$.

The $I = 1/2$ and $3/2$ spin members of the $K^\pi = 1/2^+$ band–head are found to be heavily mixed with other single–particle orbitals from the $N = 4$ and 6 oscillator shells. The interaction matrix element (30 keV) to these states is deduced from a simple three state mixing calculation.

The unperturbed energy position of the $K = 1/2^+$ structure shows a bunching around the $I, K^\pi = 1/2, 1/2^+$ band–head. The extracted energy gap of 169 kev between the band–heads of the aligned and antialigned states is nicely reproduced by our calculations within the Quasiparticle–Core Coupling Model of Dõ nau and Frauendorf. The spin sequence is however not reproduced in a satisfactory way. Comprehensive calculations with matrix elements from current more realistic core models are in progress.

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Figure Captions

Fig. 1 Tau-particles measured in coincidence with γ-rays.

Fig. 2 Gamma-ray *Ge* spectra in coincidence with τ-particles leading to levels in ^{161}Dy. The regions of excitation energies are indicated.

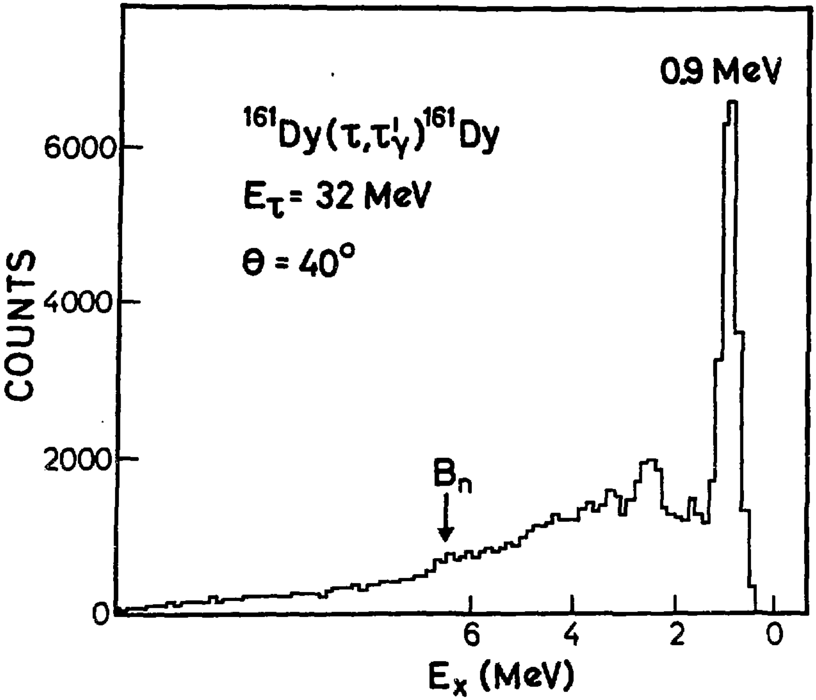
Fig. 3 The upper part (a) displays the vibration peak observed in the (τ,τ') reaction. In the (d,d') reaction [5] (d) this peak is resolved. Spectra (b) and (c) are constructed by using the information from the *Ge* detector (see the text).

Fig. 4 Partial decay scheme for levels populated in the $^{161}Dy(\tau,\tau')^{161}Dy$ reaction.

Fig. 5 Comparison between the $\Delta N = 2$ coupling results and the (d,d') cross sections [5] (normalyzed to unity). The theoretical bars in the two upper parts represent the vibrational $K_o - K_\gamma$ components in the wave functions.

Fig. 6 Comparison between the $\Delta N = 2$ coupling results and the (d,t) cross sections [6] (normalyzed to unity). The theoretical bars in the two upper parts represent the $N = 4$ components in the wave functions.

Fig. 7 Experimental level scheme for the excited $K_o \pm K_\gamma$ states in ^{161}Dy (left) compared with the average excitation energy of the $K^\pi = 2^+ \gamma$-vibrational states in ^{160}Dy and ^{162}Dy (right). In the middle part is shown the unperturbed energies of the vibrational states when their interaction with the $N = 4$ and 6 states have been removed (*table* 2).



0.9 MeV
^{161}Dy(τ,τ'γ)^{161}Dy
E_τ = 32 MeV
θ = 40°
6000
4000
2000
0
COUNTS
B_n
6
4
2
0
E_x (MeV)

Fig.1

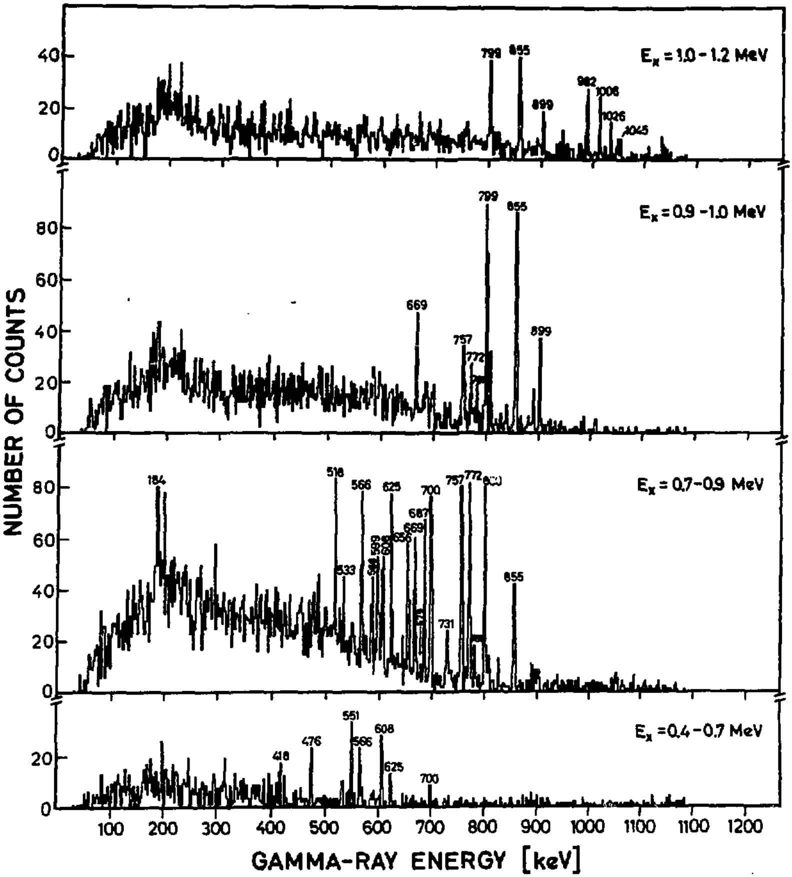

E$_x$ = 1.0 - 1.2 MeV
799
855
899
982
1008
1026
1045
E$_x$ = 0.9 -1.0 MeV
669
757
772
799
855
899
E$_x$ = 0.7-0.9 MeV
184
518
533
566
584
599
608
625
656
669
687
700
731
757
772
800
855
E$_x$ = 0.4-0.7 MeV
418
476
551
566
608
625
700
NUMBER OF COUNTS
0
20
40
60
80
100
200
300
400
500
600
700
800
900
1000
1100
1100
1200
GAMMA-RAY ENERGY [keV]

Fig.2

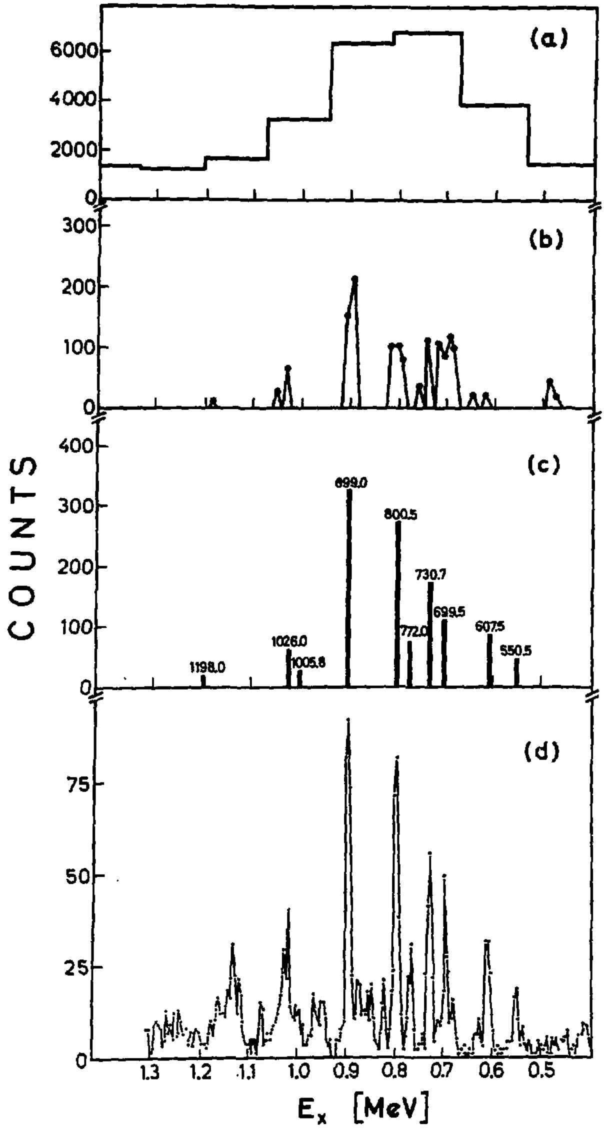

(a)
6000
4000
2000
0
(b)
300
200
100
0
(c)
400
300
200
100
0
699.0
800.5
730.7
699.5
772.0
607.5
550.5
1026.0
1005.8
1198.0
(d)
75
50
25
0
COUNTS
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
E_x [MeV]

Fig.3

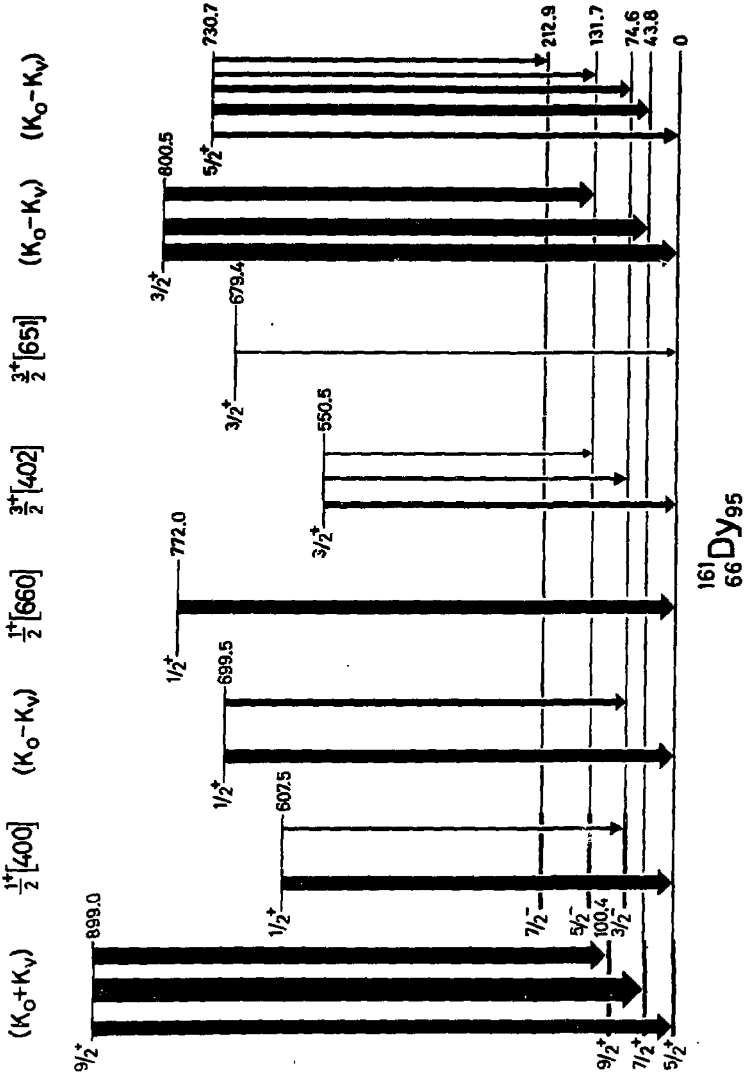
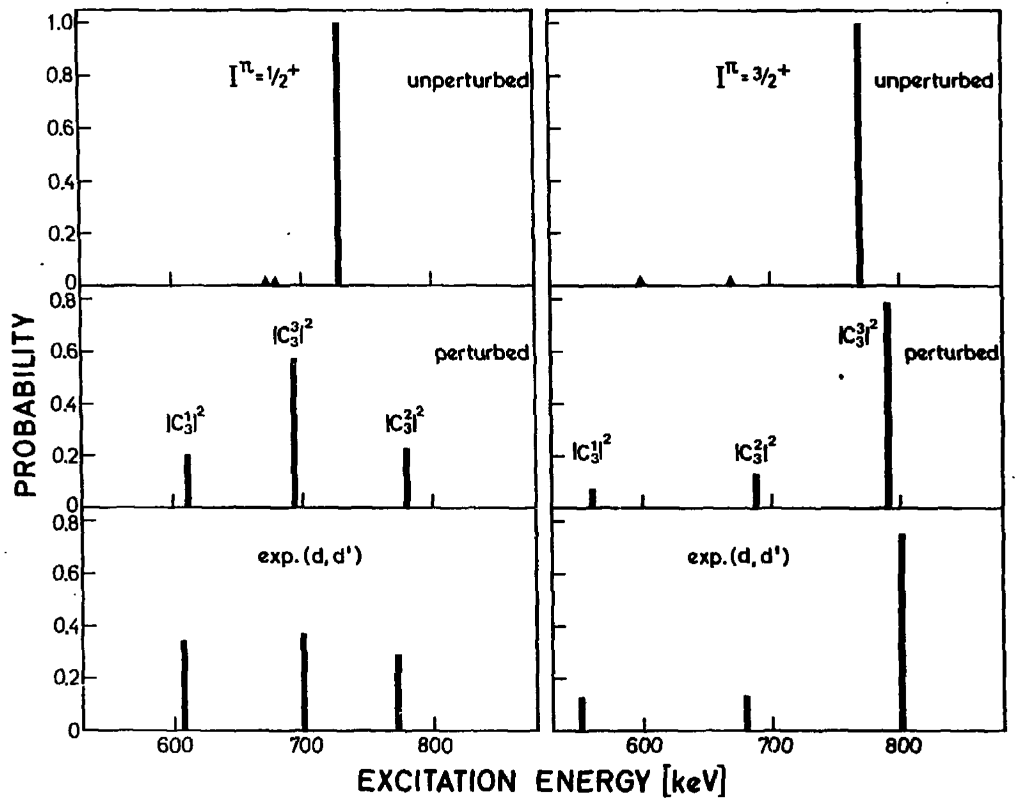

(K$_o$+K$_v$)
$\frac{1}{2}^+$[400]
(K$_o$-K$_v$)
$\frac{1}{2}^+$[660]
$\frac{3}{2}^+$[402]
$\frac{3}{2}^+$[651]
(K$_o$-K$_v$)
(K$_o$-K$_v$)
9/2$^+$
899.0
1/2$^+$
607.5
1/2$^+$
699.5
1/2$^+$
772.0
3/2$^+$
550.5
3/2$^+$
679.4
3/2$^+$
800.5
5/2$^+$
730.7
212.9
131.7
74.6
43.8
0
7/2$^-$
5/2$^-$
100.4
3/2$^-$
9/2$^+$
7/2$^+$
5/2$^+$
$^{161}_{66}$Dy$_{95}$

Fig.4



PROBABILITY
1.0
0.8
0.6
0.4
0.2
0
$I^{\pi}=1/2^+$
unperturbed
$I^{\pi}=3/2^+$
unperturbed
perturbed
$|C_3^1|^2$
$|C_3^3|^2$
$|C_3^2|^2$
perturbed
exp. (d, d')
exp. (d, d')
600
700
800
EXCITATION ENERGY [keV]

Fig. 5

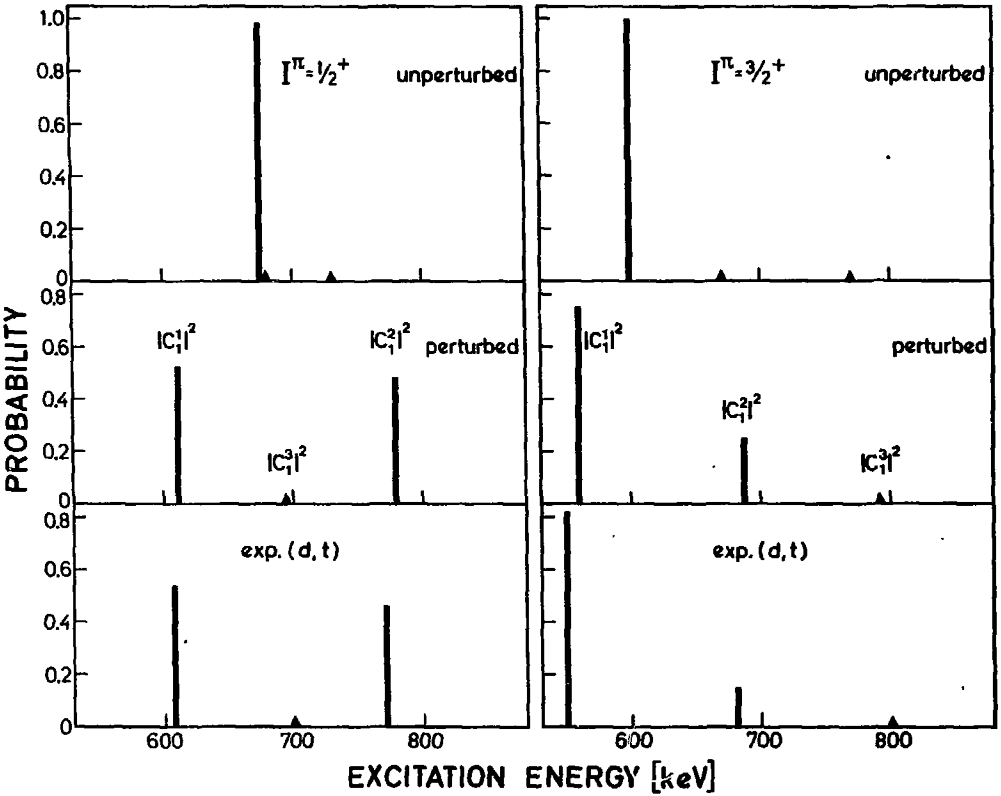

PROBABILITY
1.0
0.8
0.6
0.4
0.2
0
0.8
0.6
0.4
0.2
0
0.8
0.6
0.4
0.2
0
$I^{\pi}=1/2^{+}$
unperturbed
$|C_1^1|^2$
$|C_1^2|^2$
$|C_1^3|^2$
perturbed
exp. (d, t)
$I^{\pi}=3/2^{+}$
unperturbed
$|C_1^1|^2$
$|C_1^2|^2$
$|C_1^3|^2$
perturbed
exp. (d, t)
600
700
800
600
700
800
EXCITATION ENERGY [keV]

Fig. 6

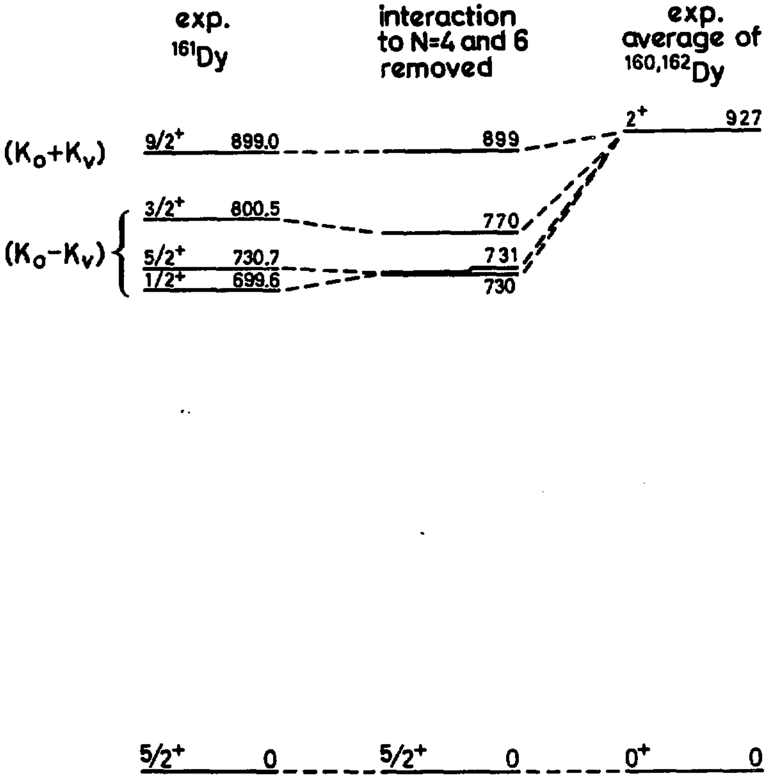

exp.
^{161}Dy
interaction
to N=4 and 6
removed
exp.
average of
^{160,162}Dy
(K_o+K_v)
(K_o-K_v)
9/2$^+$ 899.0
3/2$^+$ 800.5
5/2$^+$ 730.7
1/2$^+$ 699.6
899
770
731
730
2$^+$ 927
5/2$^+$ 0
5/2$^+$ 0
0$^+$ 0

Fig.7

FYSISK INSTITUTTS 8 FORSKNINGSGRUPPER	DEPARTMENT OF PHYSICS RESEARCH SECTIONS
Allmennfysikk og didaktikk	General Physics
Biofysikk	Biophysics
Elektronikk	Electronics
Elementærpartikkel-fysikk	Experimental Elementary Particle physics
Faste stoffers fysikk	Condensed Matter physics
Kjernefysikk	Nuclear physics
Plasma-, molekylar- og kosmisk fysikk	Plasma-, Molecular and Cosmic physics
Teoretisk fysikk	Theoretical physics

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