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High Spin States Around A = 150

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ABSTRACT. The high spin level structures of ^{152,153}Ho were studied experimentally with the ^{122}Sn (^{35}Cl, xyzγ) in-beam reaction. In ^{152}Ho a completely new level scheme was constructed up to $E_x \approx 7.9$ MeV and $J^\pi = 27^+$ including some isomers. In ^{153}Ho about twenty so far unknown transitions were found in comparison with a recent report. The structures in both nuclei are discussed in comparison with the neighbouring nuclei.

The investigation of highly rotating nuclei in the mass region A ≈ 150 through gamma spectroscopic methods offers a good possibility to study spin - induced nuclear shape changes at high angular momentum. In this transitional mass region [N ≈ 82-86, Z ≈ 62-68] between the doubly closed $^{146}_{62}Gd_{84}$ core at one end and the well-deformed nuclei on the other Strutinsky-cranked shell model calculations predict ffor the even-even isotopes Sm, Dy, Er, etc., a shape change from spherical or slightly oblate deformation ($\gamma=60°$, $\beta \approx 0.1$) at low spins to superdeformed prolat ($\gamma = 0°$, $\beta = 0.6$) or triaxial rotors in the spin region of $J = 60\hbar$, as a function of proton and neutron number (Dudek and Nazarewicz 1985). The search for superdeformed nuclei is presently investigated with big experimental effort by several groups, so Sharpey-Schafer (1986) and co-workers reported (Nyako 1986) evidence for a superdeformed structure in $^{152}_{66}Dy_{86}$ the neighbouring even -even

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isotone of $^{153}{}_{67}Ho_{86}$, up to a spin J $\approx$ 60 ħ. Janssens (1985) investigated the behaviour of ^{153}Ho at very high spin via spectroscopy of unresolved γ-radiation and reported for states in the spin region of J $\approx$ 40 ħ the onest of a collective E2-component in the continuum γ -spectra. We extended in this work the level scheme of ^{153}Ho (Radford 1983) up to a state with E_x = 14.7 MeV, J $\approx$ (89/2 ħ) in order to resolve the so-called "Ml-quasicontinuum" and to look for collective states at the highest spins. For the odd-odd nucleus ^{152}Ho there existed no level scheme. Only some γ-ray transitions were reported in ref. (Hagman 1979, Jastrzebski 1980) to belong to this nucleus. We propose in this work a level scheme for ^{152}Ho, the only nucleus in the A=146-154 mass region for which no detailed spectroscopic information was available.

Reaction and Experimental Procedure

The high spin states in ^{152,153}Ho were populated by the ^{122}Sn(^{35}Cl,xn) reaction at E_{lab} = 167 MeV. The target consisted of 98% enriched ^{122}Sn (2 mg/cm) evaporated on a gold backing. The ^{35}Cl beam was extracted from the MP-Tandem and post-accelerator of the Max Planck Institut für Kernphysik in Heidelberg. The γ-radiation was detected with the Heidelberg double anti-Compton spectrometer consisting of two HP Ge detectors with active NaI shielding. After a total beam time of 192 hrs 6.23×10^7 coincidence events were registered. The γ-γ-Δt events were stored on magnetic tape with PDP 11/34 on-line computer. The present study involved four separate measurements: relative γ-ray excitation fuction, γ-ray angular distributions, γ-γ-coincidence measurements and γ-ray timing measurements. The relative excitation functions for the emitted γ-rays were obtained by varying the energy of the incident ^{35} Cl between 156 and 174 MeV in steps of about 6 MeV. These excitation functions which have their maxima for the (^{35}Cl, xn) reaction at 167 MeV, were used for assignments and as a means to confirm the spin assignments in ^{152,153}Ho. The angular distribution measurements were made at 6 angles, 0°, 15°, 35°, 55°, 75° and 90°, chosen to correspond to approximately uniform intervals for the values of $\cos^2\theta$. Every two hours the angle was changed to guarantee for a stability. In the γ-γ coincidence measurements, the Ge- detectors were placed at ±90° with respect to the beam axis to minimize the Doppler shift. With a beam current of 40-50 nA(^{35}Cl) the maximum counting rates with respect to energy resolution and compton suppression were achieved giving a coincidence counting rate of about 140Hz. In addition to these measurements, time spectra have been measured for all γ-transitions (Table 1). The start pulses for the TAC were obtained from a NaI (Tl) crystal at the target, and the stop pulses were taken from a Ge-detector.

Table 1. The energy and the corresponding half life for excited states in ^{152}Ho

Excitation energy (keV)	Half life (ns)
198	68 ± 11
1063	55 ± 8
1667	70 ± 15
2278	76 ± 6
2729	55 ± 10
2872	83 ± 13
3871	115 ± 10

Results and Discussion

Figures 1,2 show the proposed level schemes of ^{152,153}Ho. The main criterion for the level ordering was the intensity of the γ-transitions so that for the highly excited states and also for those in ^{152}Ho which are contaminated with ^{153}Ho and ^{152}Dy lines (E_γ = 604 keV, 712 keV, 734 keV, 759keV), as well as the E_γ = 511 keV line, the level ordering can only be tentative.

The nucleus ^{152}Ho

Because of the lack of theoretical predictions the proposed level scheme of ^{152}Ho will be discussed in light of a comparison to the experimental systematics of the N=85 isotones. For $^{152}{}_{67}$Ho85 with three protons and three neutrons outside the doubly closed $^{146}{}_{64}$Gd82 core even the ground state spin was unknown. Schmidt-Ott (1974) reported two long-lived-unstable isomers, one with $J^\pi=9^+$ and $T_{1/2}$=52 s and the other with j^π = 3^+ and $T_{1/2}$=2.4 m. The ground state spin of ^{152}Ho was chosen for this work to $J^\pi=9^+$ (Ronald 1963) in accordance with the neighbouring odd-odd isotone $^{150}{}_{65}Tb_{85}$ (Board 1979) and odd-odd isotope $^{150}{}_{67}$Ho. (Schmidt - ott 1974). This would correspond to the aligned $[\pi h^3{}_{11/2}]_{11/2}$ X $[\nu f^3_{7/2}]_{7/2}$ shell model configuration which can also be found in $^{148}{}_{63}$Eu85 (Piiparinen 1981). The striking similarities for energy spacing and spin of the states in nuclei

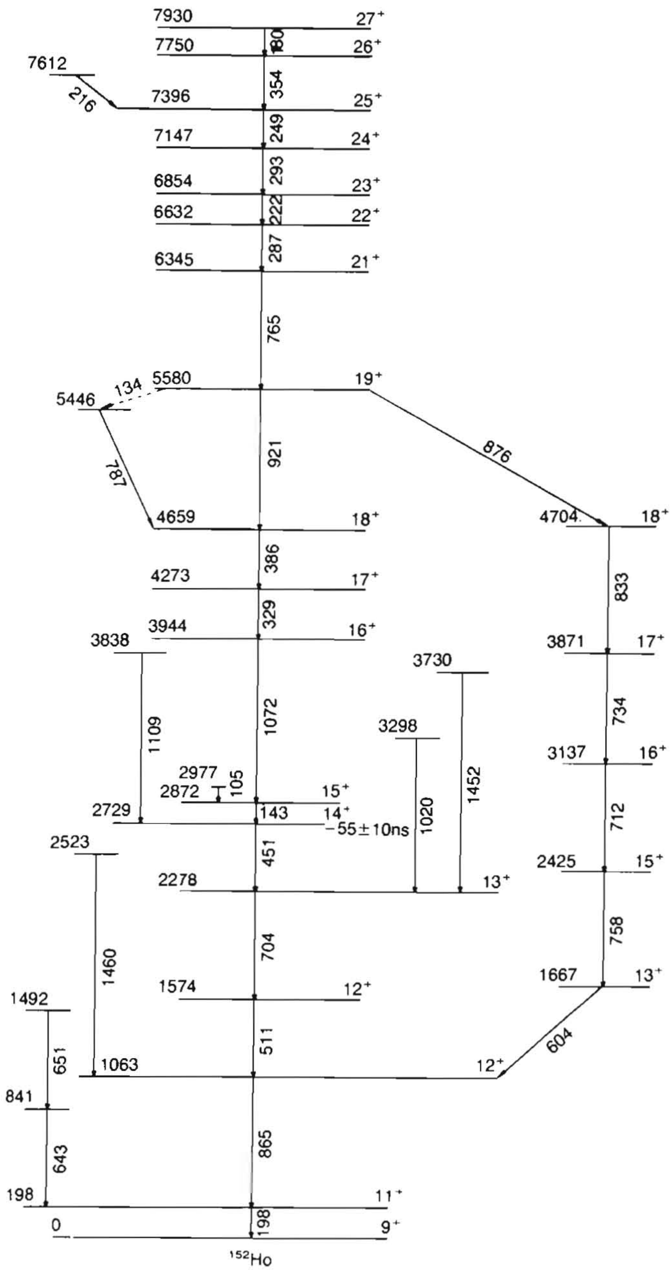


Fig. 1. The proposed level scheme for ^{152}Ho as established by the present work (Mansour 1986)

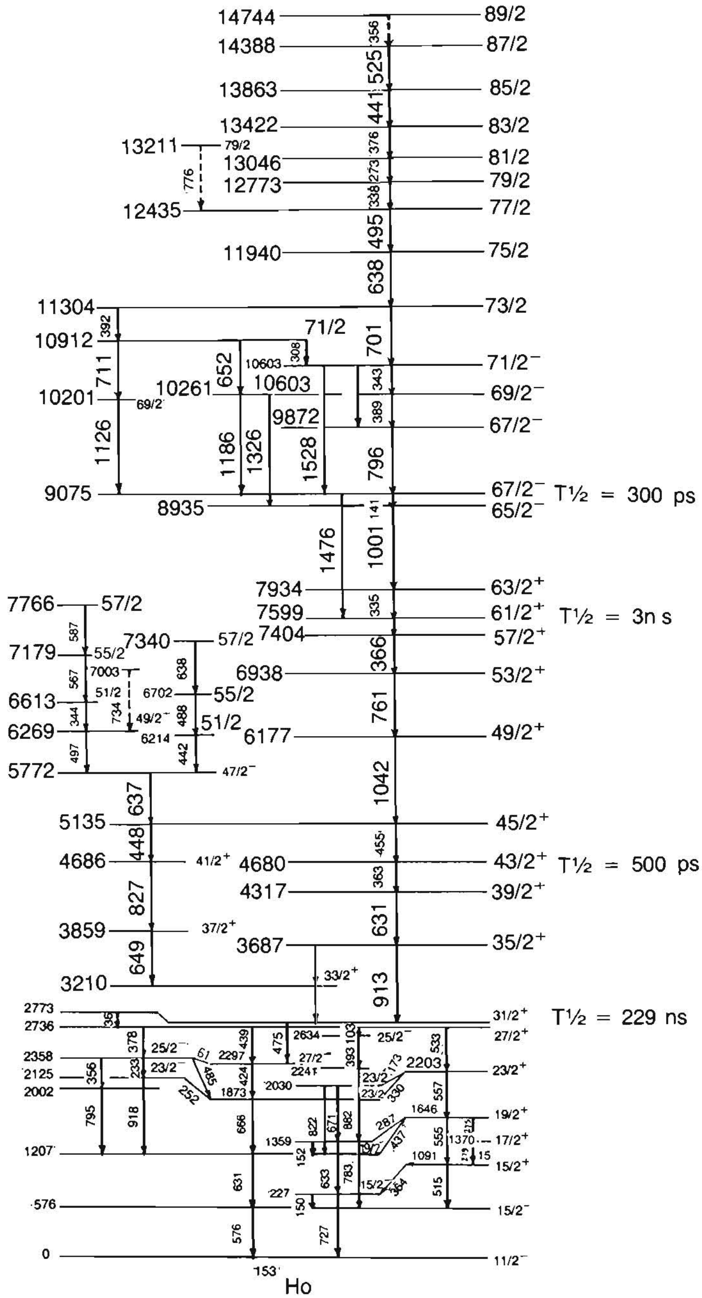


Fig. 2. The proposed level scheme for ^{153}Ho. The dashed transitions indicate the uncertain ordering.

belonging to isotone chains with Z=62-68 in the mass region A-150 is demonstrated in Fig. 4 a,b and c where three chains are displayed with N=84,85, 86. The experimental information on $^{146-148}Sm$ and $^{147-149}Eu$, $^{148-150}Gd$, $^{149-151}Tb$, $^{150-153}Dy$, and $^{152-154}Er$, was taken from [Radford (1983), King (1978), Piiparinen (1979, 1980, 1981), Hammaren (1979), Fleissner (1977), Kleinheinz (1979) Broda (1979), Kemnitz (1978), Gizon (1981), Bastin (1980), Carlen (1982) and Aguer (1979).

For all even Z members of this chain $\nu f^3_{7/2}$ and $\nu h_{9/2}\, f^2_{7/2}$ shell model multiplets are reported to feed directly into the ground state. For $^{150}{}_{65}Tb_{85}$ which is the only odd-odd N=85 nucleus with known level pattern ref. (Broda (1979) reported a similar structure, namely a $J^\pi=9^+$ ground state fed by $\pi\, h_{11/2} \times \nu h_{9/2}\, f^2_{7/2}$ and $\pi\, h_{11/2} \times \nu f^3_{7/2}$ multiplets. In this situation it seems reasonable to compare the ground state band of ^{152}Ho with these well-established level schemes. From the γ-γ coincidence spectra it appears that ten γ-rays in two groups are always in coincidence. They are the strongest in the single spectrum and their intensities represent more than 70% of the total intensity of discrete lines assigned to the ^{152}Ho exit channel in the ^{122}Sn + ^{35}Cl reaction.

The four levels based on the 1063 keV state decay by the 604, 758, 712 and 734 keV γ-rays which contaminated by a lines of similar energy in ^{153}Ho, ^{152}Dy. The intensities of these transitions are too week to allow the assignment of each line to a definite place, and consequently, the ordering of the 604, 758, 712 and 734 keV γ-cascade is tentative. In Fig. 4b the ^{152}Ho states with E_x = 198 keV, 1063 keV, 1574 keV, 2025 keV and 2729 keV are compared with the $\nu h_{9/2}\, f^2_{7/2}$ structures of the even z isotones and the $h_{11/2} \times \nu h_{9/2}\, f^2_{7/2}$ multiplet in $^{150}{}_{65}Tb_{85}$. This comparison shows that the energy spacings between the excited states and the ground state are in good agreement with the neighbouring isotones. Also the comparison with the level schemes of the neighbouring isotones as well as the plots of the yrast energies versus I(I+I) given in Fig. 3, show that the new level scheme of ^{152}Ho fits well into the systematics of this mass region.

Also the decline of the energy of the first excited state with increasing Z fits into this systematics if one takes into account that nuclei in this mass region are reported to exhibit increasing oblate (ε = 0.1 = β = 0.11) deformation if protons are added to the core (Andersson 1976). The Nilsson diagram shows that the energy gap between the $\nu f_{7/2}$ and $\nu h_{9/2}$ states is decreasing with growing oblate deformation. This would favour the promotion of a neutron into the $\nu h_{9/2}$ shell and

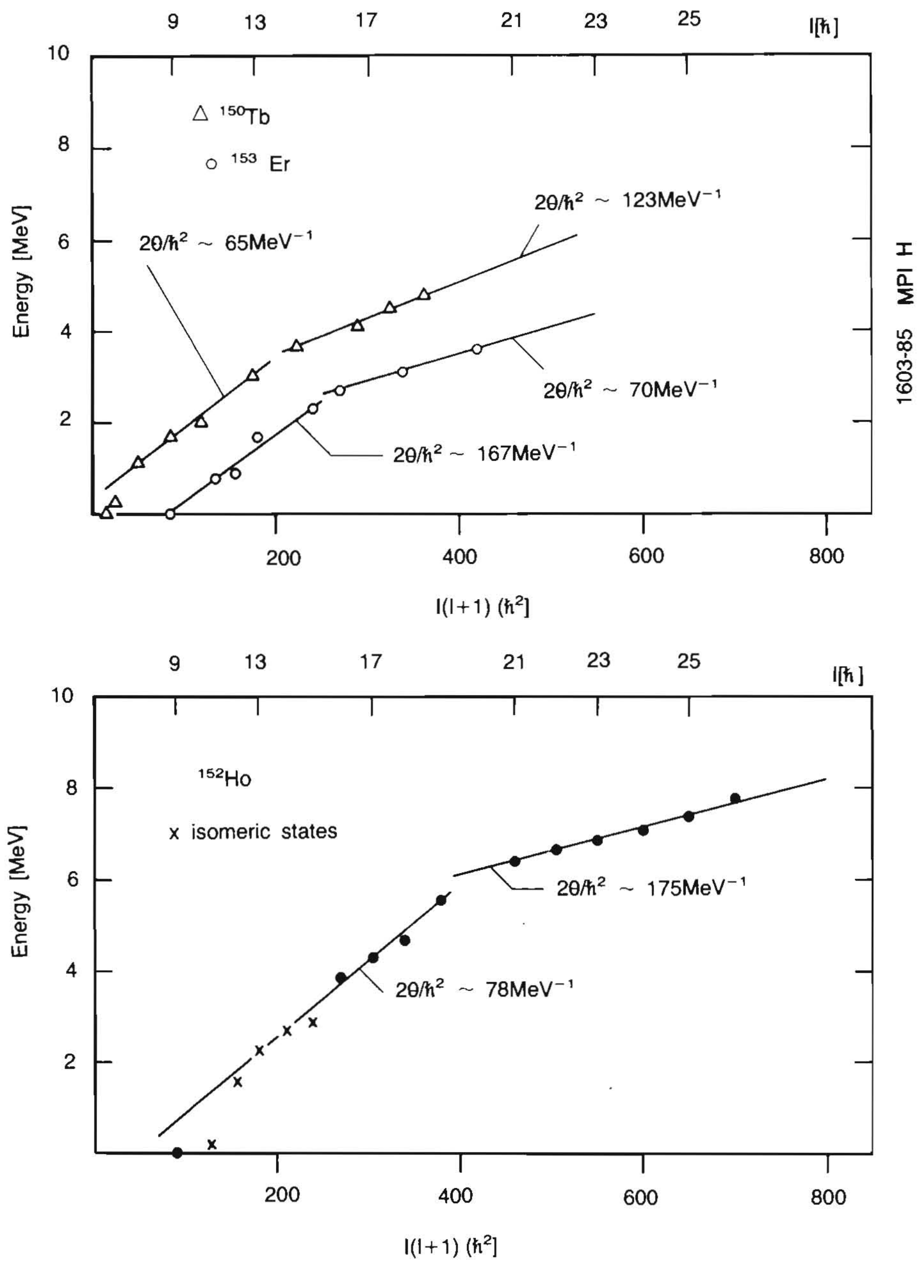


Fig. 3. Excitation energy of the yrast states in ^{152}Ho and the neighbouring ^{150}Tb (Broda 1978), ^{153}Er (Horn 1981) nuclei versus I (I+1). The average effective moments of inertia are indicated.

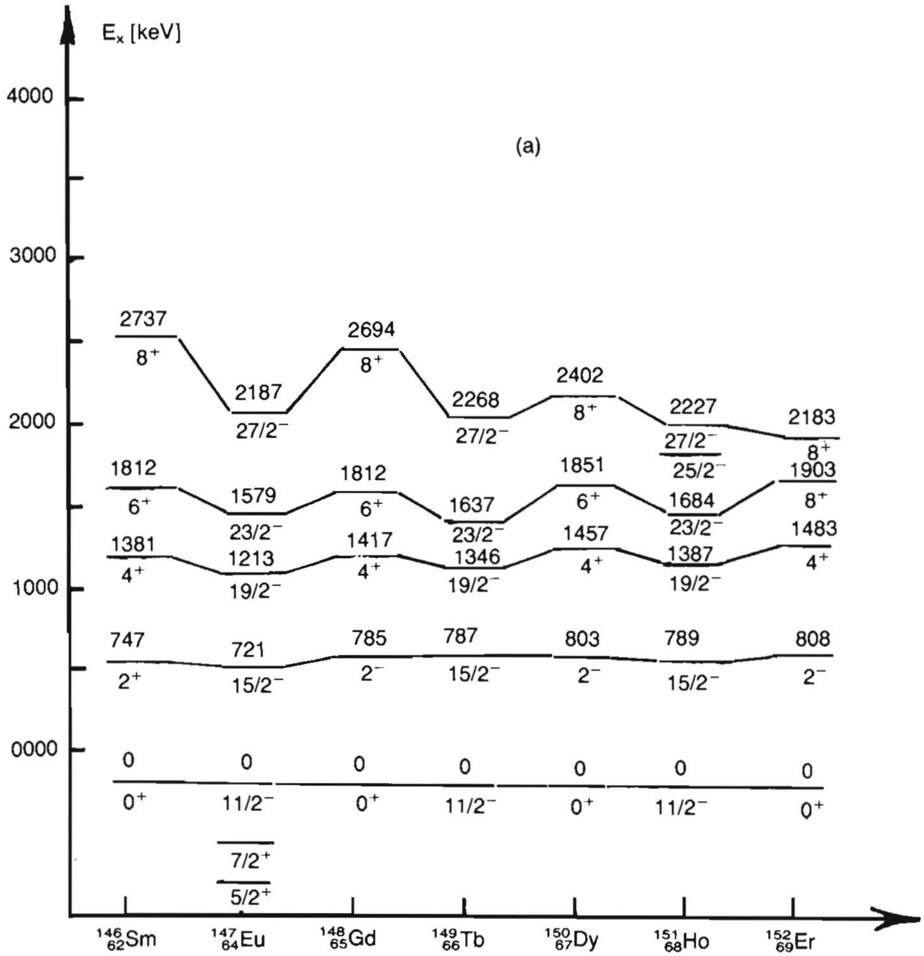
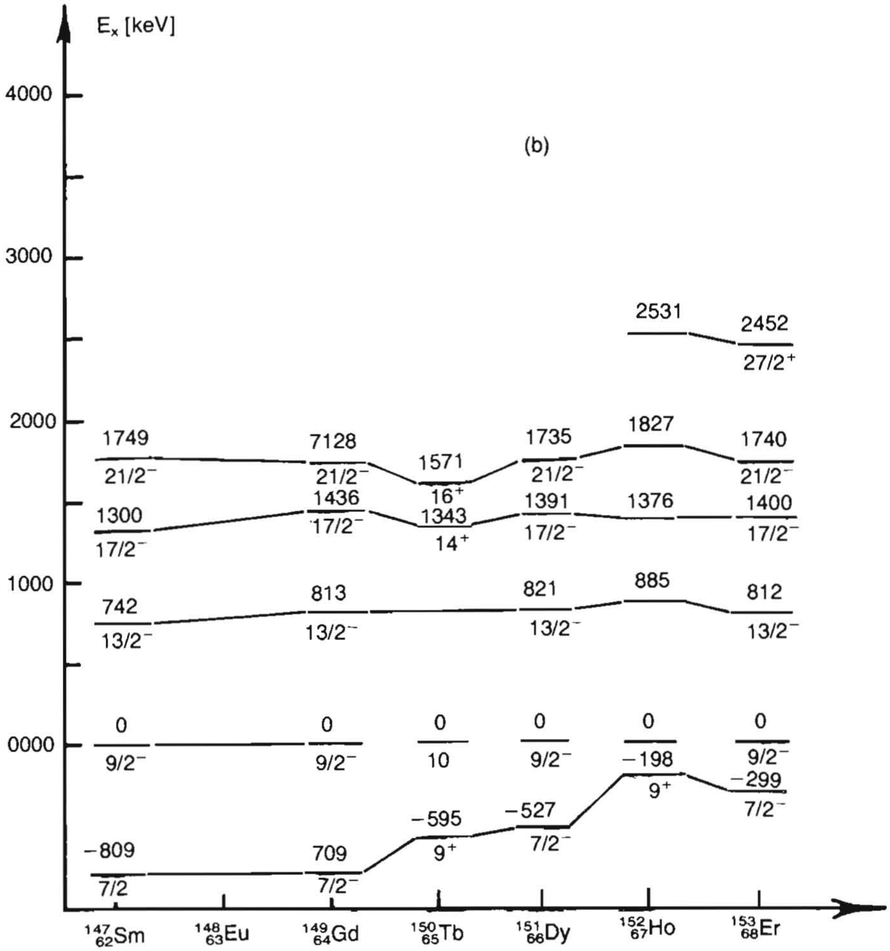
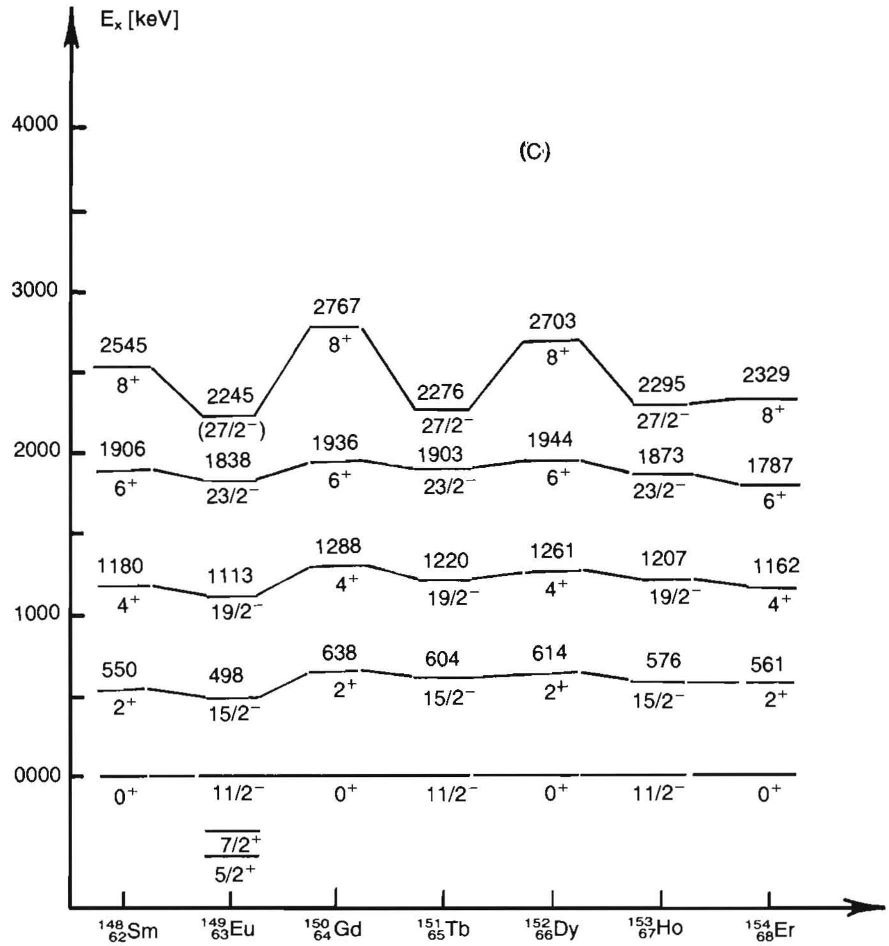


Fig. 4.a,b,c. Similarities which can be found in this mass region N=84(a), N=85(b) and N=86 isotones


E_x [keV]
4000
3000
2000
1000
0000
(b)
2531
2452
27/2+
1749
21/2−
7128
21/2−
1571
16+
1735
21/2−
1827
1740
21/2−
1300
17/2−
1436
17/2−
1343
14+
1391
17/2−
1376
1400
17/2−
742
13/2−
813
13/2−
821
13/2−
885
812
13/2−
0
9/2−
0
9/2−
0
10
0
9/2−
0
−198
9+
0
9/2−
−299
7/2−
−595
9+
−527
7/2−
−809
7/2
709
7/2−
147 62 Sm
148 63 Eu
149 64 Gd
150 65 Tb
151 66 Dy
152 67 Ho
153 68 Er



Ex [keV]
4000
3000
2000
1000
0000
(C)
2545
8+
2245
(27/2−)
2767
8+
2276
27/2−
2703
8+
2295
27/2−
2329
8+
1906
6+
1838
23/2−
1936
6+
1903
23/2−
1944
6+
1873
23/2−
1787
6+
1180
4+
1113
19/2−
1288
4+
1220
19/2−
1261
4+
1207
19/2−
1162
4+
550
2+
498
15/2−
638
2+
604
15/2−
614
2+
576
15/2−
561
2+
0+
11/2−
0+
11/2−
0+
11/2−
0+
7/2+
5/2+
148 62 Sm
149 63 Eu
150 64 Gd
151 65 Tb
152 66 Dy
153 67 Ho
154 68 Er

lower the energy of the first excited state if it belongs to a $\pi h^3_{11/2} \times h_{9/2} f^2_{7/2}$ multiplet. The assumption for an oblate deformation of the ^{152}Ho nucleus is furthermore supported by the irregular energy spacing and the occurrence of ns isomers which indicate a single particle excitation mode. The spin assignments to ^{152}Ho deduced from the evaluation of the γ-ray angular distributions are consistent with the systematics of the nuclei in the N=85 isotone chain.

The long lifetimes reported by Jastrezbski (1980) were also observed in this work, together with the information from the coincidence spectra (Fig. 5), the measured $T_{1/2}$ values indicate an isomeric state at E_x=2729 keVwith$T_{1/2}$=55±10 ns. Since γ-transitions placed above this state were also found to be delayed a second isomer at higher excitation energy can be suggested but not located in the level scheme due to the big statistical errors.

The nucleus ^{153}Ho

The spherical or slightly oblate shape along the yrast line in the mass region A=150 manifests itself in an irregular excitation energy pattern due to the alignment of individual nucleons along the symmetry axis. Theoretical calculations predict the coexistence of these oblate yrast states with prolate deformed states-3 MeV above the yrast line. This prolate "phase" is reported to become yrast only in the spin region of J=60ħ (Dudek and Nazarewicz 1985). The spectroscopy of these collective bands is very difficult due to the fact that no interaction of the oblate yrast states and the prolate rotational bands is expected in the low spin region. Since the yrast states are preferentially populated in fusion-evaporation reactions the intensity of the γ-transitions between the collective states is very low. So the only chance to prove the existence of these strongly deformed bands with discrete γ-γ coincidence measurements is to enlarge the spectroscopic information along the yrast line up to the region where the rotational bands gets yrast. Janssens (1985) reported for the spin range of $\langle J \rangle \approx 44\hbar$-$49\hbar$ an onset of a collective E2 component originating from the collective yrast states.

In this work the level scheme of ^{153}Ho Fig. 2 was extended up to a state with $E_x \approx$ 14.744 MeV and J = (89/2 ħ). More than 20 new transitions were added to the level scheme of Radford (1983). Up to the highest spins an irregular energy spacing of the excited states can be observed which manifests an excitation by single particle alignment. A strong interaction of the oblate and prolate states up to this excitation energy seems unlikely.

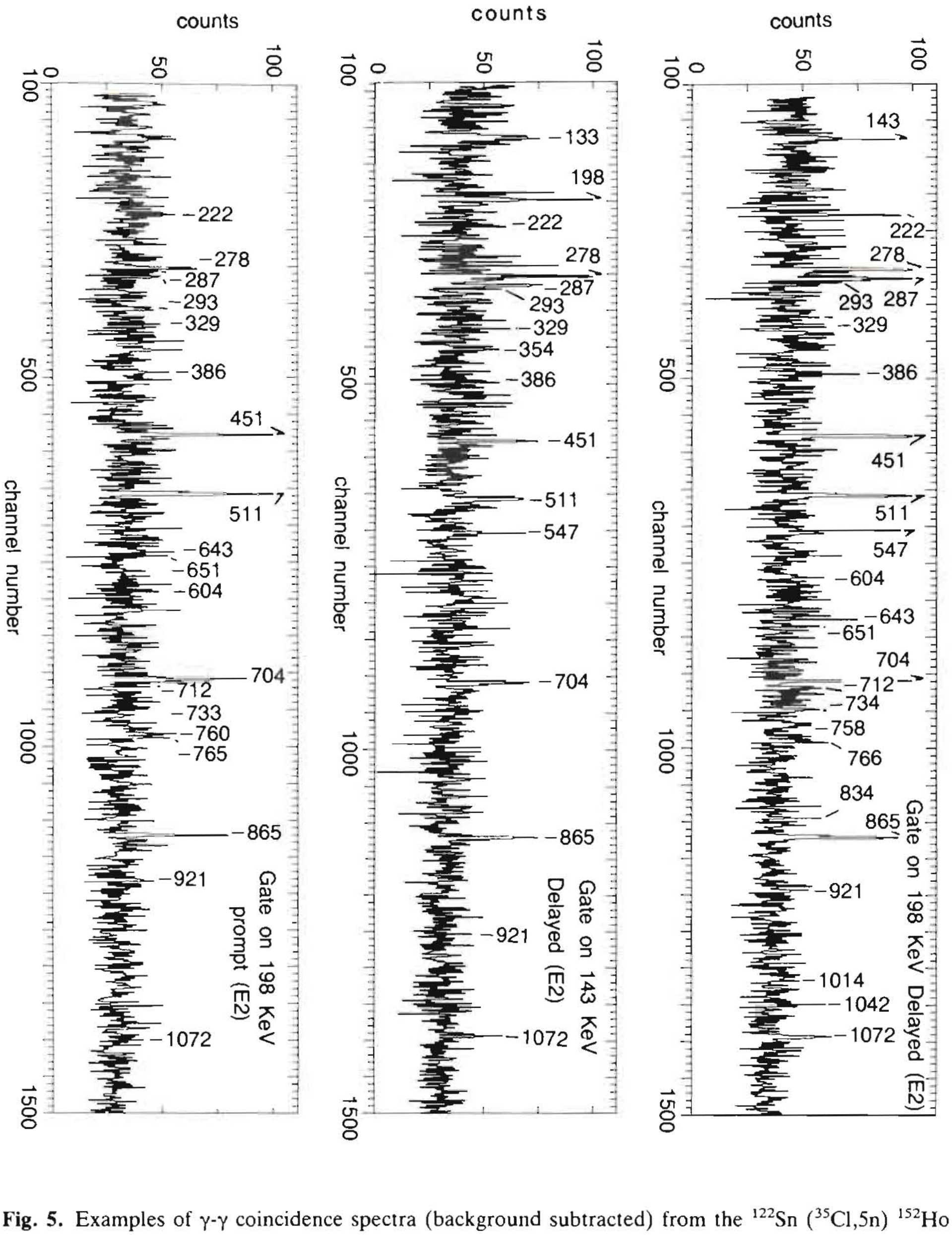


Fig. 5. Examples of γ-γ coincidence spectra (background subtracted) from the ^{122}Sn (^{35}Cl,5n) ^{152}Ho reaction at 167 MeV.

Conclusion

The level structure of high spin states in ^{152}Ho and ^{153}Ho has been investigated and compared to the systematic observed for the neighbouring istopes. Informations from coincidence spectra, angular distribution and exictation functions allowed to construct a completely new level scheme for ^{152}Ho. Low energy dipole strength (probably M1) occurs at very high spin in ^{153}Ho.

References

Aguer, P. (1979) Lifetimes of high-spin yrast states in ^{154}Er, *Phys. Lett.* Vol. 828, 55-59.

Andersson, G. (1976) Nuclear shell structure at very high angular momentum, *Nucl. Phys.* Vol. 268A, 205-213.

Bastin, G. (1980) High spin states in the N=84 Nucleus ^{152}Er, *Nucl. Phys.* Vol. 345A, 302-310.

Broda, R. (1979) Yrast states in the four-particle nucleus ^{150}Tb, **Proc.** "Symp. on high spin phenomena in nuclei" Argonne 401, pp. 28-29.

Carlen, L. (1982) High spin states and yrast isomerism in ^{153}Er, *Nucl. Phys.* Vol. 381A, 155-165.

Dudek, J. and **Nazarewicz, W.** (1985) Shape evolution in the transitional gadolinium, dysprosium, erbium, and ytterbium nuclei, *Phys. Rev.* Vol. 31c, 298-301.

Fleissner, J.G. (1977) Band structure in ^{143,149,151}Eu observed via (HI,xn) reactions, *Phys. Rev.* Vol. 16c, 227-238.

Gizon, J. (1981) The 235 ns g+ isomer in $^{148}_{63}$Eu, Z. *Phys.* Vol. 310A, 67-74.

Hagman, D.C.J.M. (1979) Search for high spin isomeric states in the rare earth region, *Phys. Lett.* Vol. 848, 301-309.

Hammaren, E. (1979) Structural connections between ^{148}Sm and ^{149}Sm nuclei, *Nucl. Phys.* Vol. 321A, 71-76.

Horn, D. (1981) High spin single particle states in ^{152},^{153}Er, *Phys. Rev.* Vol. 23c, 1047-1055.

Janssens, R.V.F. (1985) Kx-ray yields M1 strength and the γ-ray quasicontinuum in ^{153}Ho, *Phys. Lett.* Vol. 152B, 167-170.

Jastrzebski, J. (1980) Unambiguous identification and properties of high spin isomers in nuclei close to N=82, *Phys. Lett.* Vol. 97B, 50-54.

Kemnitz, P. (1978) In beam study of high spin few particle states and the decay of an 11/2 isomer in ^{151}Tb, *Nucl. Phys.* Vol. 311A, 11-28.

King, C.H. (1978) High spin states in ^{146}Sm, *Phys. Rev.* Vol. 5c, 2127-2136.

Kleinheinz, P. (1979) Particle hole yrast states in ^{146}Gd and ^{147}Gd and the Z=64 shell closure, Proc. "Symp. on high-spin phenomena in nuclei" Argonne 407, pp. 279-295.

Mansour, N. (1985) Hochspinzustände Um A ~ 150 Ann. report in Max-planck Institut für kernphysik Heidelberg, pp. 80-81.

Mansour, N. (1986) High spin states in ^{152},^{153}Ho, Int. symp. on weak and electromagnetic interactions in nuclei Heidelberg, Germany, pp. 585-586.

McNeill, J. (1986) Level structure of proton-rich N=83 nuclei ^{150}Ho and ^{152}Tm, *Z. Phys.* Vol. 325A, 27-33.

Nyako, B. (1986) Coexistence of prolate and oblate sructure up to spin 40ħ in ^{152}Dy, *Phys. Rev. Lett.* Vol. 56, 2680-2684.

Piiparinen, M. (1979) Symp. on high-spin phenomena in nuclei, Argonne 407.

Piiparinen, M. (1980) Proc. "Int. conf. on nucl. Behaviour at high angular momentum, Strasbourg 53.

Piiparinen, M. (1981) High spin shell model excitation in ^{149}Cd, *Z. Phys.* Vol. 300A, 133-138.

Radford, D.C. (1983) Very high spin states and isomerism in ^{153}Ho, *Phys. Lett.* Vol. 126B, 24-27.

Ronald, D. (1963) Alpha decay properties of some Holmium isotopes near the 82-neutron closed shell, *Phys. Rev.* Vol. 130, 1491-1498.

Schmidt-Ott, W.D. (1974) γ-decay branching ratios for high-and low spin isomers in ^{151,152,153,154}Ho, *Phys. Rev.* Vol. 10c, 296-306.

Sharpey-Schafer, J.F. (1986) Shape coexistence and discrete Super deformed states up to 60ħ in ^{152}Dy, Int. symp. on weak and electromagnetic interactions in nuclei Heidelberg, Germany, pp. 195-205.

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مستويات الطاقة عالية الغزل حول المنطقة ذات الوزن الذرى أ = ١٥٠

***نصيف منصور و [١]أندرياس بيبكا و علي موساقى**
هلبرت إتسانشس و يوسف متسنجر و هانس كلابدور
[٢]بيومي طرطور و زكريا عواد

[١]معهد ماكس بلانك للطبيعة النووية ـ هيدلبرج ـ ألمانيا الغربية
[٢]كلية العلوم ـ قسم الطبيعة ـ جامعة الزقازيق ـ الزقازيق ـ مصر

لاقى موضوع مستويات الطاقة ذات الغزل العالي دراسة نظرية ومعملية مكثفة، وأهم هذه الطرق إستخداما التفاعل الآيونى الثقيل المركب المصحوب بتصعيد البروتونات والنيوترونات وأشعة ألفا وأشعة جاما والذي يترك النواة في حالة إثارة عالية.

يناقش هذا البحث باستخدام هذا التفاعل خطة المستوى لنواة الهلميوم ذات الوزن الذري ١٥٣ فردية البروتونات إلى الغزل ٢/٨٩ وهو أعلى غزل في هذه المنطقة إلى الان، وتم أيضا وضع خطة المستوى لنواة الهلميوم ذات الوزن الذري ١٥٢ فردية البروتونات والنيوترونات لأول مرة إلى طاقة ٧,٩ م.ا.ف وغزل ٢٧+ بالإضافة إلى قياس طيف الزمن لكل الانتقالات الجامية في خطة المستوى وأخيرا تمت مناقشة هذه النتائج ومقارنتها بالنويات المجاورة.

* يعمل في كلية العلوم جامعة الزقازيق.