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LEVELS IN ^{159}Ho AS POPULATED FROM DECAY OF ^{159}Er

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The level scheme of the odd proton nucleus ^{159}Ho has been investigated using Ge (Li) and Si (Li) detectors. Results of γ-ray singles, conversion electron spectra and coincidence experiments are reported. Assignments are made for several energy levels.

I. INTRODUCTION

The nucleus ^{159}Ho has been studied by several authors. ABDURAZAKOV et al [1] identified the nucleus ^{159}Er and its half-life ($T_{1/2}$ = 36 ± 1mn) has been measured by LAGARDE et al [2] . In a subsequent paper ABDURAZAKOV et al [3] ascribed the NILSSON configurations $7/2^-$ [523] , $1/2^+$ [411] , $5/2^-$ [532] and $5/2^+$ [413] to the ground state, the 205.8 keV level, 624.4 keV level and 649.5 keV level, respectively. The decay of the isomeric state $1/2^+$ [411] has been studied by BORGREEN et al [4] who measured the half-life $T_{1/2}$ = 6.9s and by GEIGER et al [5] who found a value slightly different ($T_{1/2}$ = 8.30 ± 0.08s) and provided the decay scheme of the isomeric state.

In an extensive review of deficient neutron nuclei, GROMOV et al [6] added three levels to the $1/2^+$ [411] band and found the energies of the of $3/2^+$ [411] and $1/2^-$ [541] intrinsic states.

Of great interest is the recent study of PANAR et al [7] which has been performed by means of ^{158}Dy (α,t) ^{159}Ho and ^{158}Dy (^{3}He, d) ^{159}Ho reactions. Many of the ambiguities which perplexed the results obtained by radioactive decay have been cleared up in these transfer reaction studies. Nuclear data sheets [8] give a list of twenty γ-transitions belonging to the ^{159}Ho nucleus.

A few studies were carried out by in-beam spectroscopy [9, 10, 11] by means of $^{159}Tb(\alpha, 4n)^{159}Ho$ reactions. They only established the ground state band. In ref. [11] some possibilities for the existence of other bands are indicated, however without precise assignments. ADAM et al [12] made an attempt to establish two other rotational bands.

Therefore we do not have a very clear picture of the behaviour of this nucleus and it is the reason why it was decided to devote ourselves to a new study of the energy levels of ^{159}Ho obtained by the decay of ^{159}Er.

II. EXPERIMENTAL METHODS

The ^{159}Er nucleus has been produced by the ^{165}Ho (p, 7 n) ^{159}Er reaction in the ORSAY synchro cyclotron beam. Enriched samples were prepared by means of the isotope separator. Since the chain of radioactivr decays.

$^{159}Er \rightarrow {}^{159}Ho \rightarrow {}^{159}Dy \rightarrow {}^{159}Tb$ is obtained it is necessary to know the γ-transitions of the daughter products. The results with respect to the decay $^{159}Ho \rightarrow {}^{159}Dy$ were extracted from ref. [13] and from complementary experiments performed at the Grenoble cyclotron. The reaction $^{159}Tb(\alpha, 4n)$ ^{159}Ho allows one either to prepare ^{159}Ho samples or to study the decay of possible isomeric states using the pulsed cyclotron beam. The study of the ^{159}Er decay is severely complicated by the rapid growth of the activity of the daughter ^{159}Ho. There are few γ-rays coming from the decay $^{159}Dy \rightarrow {}^{159}Tb$.

The single γ-ray spectra have been recorded using 1 cm^3 and 20 cm^3 Ge (Li) detectors (resolution 0.8 keV at 100 keV and 2.5 keV at 1332 keV respectively). The conversion electron spectra were measured with a Si(Li) detector (resolution 2 keV at 600 keV). This detector was placed in a uniform magnetic field device which has been described in ref [14]. The γ-γ coincidence measurements have been performed with Ge(Li) detectors of 20 and 25 cm^3 volume. The time resolution was about 25 ns.

III. EXPERIMENTAL RESULTS

The energies, intensities and multipolarities of ^{159}Er γ-rays are summarized in table 1. Peaks of the daughter products (about 70) are not tabulated. In this table about thirty peaks of rather low intensity have not been cited ; they could not be placed in the decay scheme Table 1 lists 110 γ-rays from which only 55 have been placed in the decay scheme. But, we must point out that the intensity of the assigned transitions correspond to about 90% of the total disintegration intensity. The results of the γ-γ coincidence experiments are presented in table 2. Typical γ-ray and conversion-electron spectra are presented in figs. 1-2. The excitation energy systematics in $^{157-165}Ho$ nuclei for different orbitals are drawn in fig. 3.

IV. DISCUSSION OF THE RESULTS

4.1. The ground state rotational band

It is well known that the ground state is the $7/2^-$ [523] NILSSON state [3, 4, 5, 7]. The first member of the rotational band ($I = 9/2^-$) is observed at 97.5 keV in agreement with the in-beam results [9, 10, 11].

4.2. The $1/2^+$ [411] and $7/2^+$ [404] bands

From the bombardment of Dy targets with a pulsed proton beam BORGREEN et al [4] , as well as GEIGER et al [5] have established the existence of an isomeric state at 205.9 keV. The half-life of this state has been found to be 8.30 ± 0.08 s. by GEIGER et al [5] . Moreover they infer that the 205.9 keV level decays on one hand, by an E3 transition and on the other hand, by a cascade involving a 40 keV M3 γ-transition and a 165.9 keV E1 γ-transition. The 205.9 keV and 165.9 keV levels are identified as the NILSSON orbitals $1/2^+$ [411] and $7/2^+$ [404] respectively. In our experiments the 165.9 keV E1 and 205.9 keV E3 transitions confirm these results.

The coincidence between the 132.1 keV γ-ray and a 166 keV γ-ray suggests the existence of a level at 298.0 keV which could be the first rotational level of the $7/2^+$ [404] band. If this assumption is correct the apparent moment of inertia parameter would have the value 14.7 keV which is slightly larger than the corresponding one in ^{161}Ho (13.1 keV), ref [15, 16] . This 298.0 level could also be the band head of the $3/2^+$ [411] NILSSON state which is located at 298.7 keV in ^{161}Ho. In such a case, the transition between this level and the $3/2^+$, $1/2^+$ [411] and $1/2^+$, $1/2^+$ [411] levels should have been found : in spite of a careful analysis we have not be able to observe them. Of course, the knowledge of the multipole order of the 132.1 keV transition would finally settle the difficulty. This peak is contaminated with a strong γ-ray from the daughter ^{159}Dy, so that it is impossible to obtain results accurate enough to decide between an E2 or an M1 multipolarity.

From all our experimental results we find two levels at 212.7 and 312.8 keV whose energy spacings and spin sequence are such that they are good candidates for the first two rotational levels of the $1/2^+$ [411] state which is very well established at 205.9 keV. Our energy values disagree with those of GROMOV et al [6] (222.1 and 328.2 keV) but are in very good agreement with those of PANAR et al [7] (212 and 315 keV). The values of the moment of inertia parameter (11.4 keV), of the decoupling parameter (-0.80) and of the energy spacing between the $3/2^+$ and $1/2^+$ levels (6.8 keV) fit very well with the systematics of this $1/2^+$ [411] band and strongly support our interpretation.

4.3. The $5/2^+$ [402] state.

In our spectrum a very intense 252.9 keV γ-ray has been observed. It is known to belong to the decay of the daughter ^{159}Ho. However, six γ-rays unobserved in the decay of ^{159}Ho are unambiguously appearing in our γ-γ coincidence experiments wherever a gate on this energy has been placed with the result that there is a definite γ-ray having the same energy in the parent. Besides there is one more piece of evidence, based on arithmetical considerations, for such a conclusion : in adding the energy values of three of these six γ-rays to the energy of the gating γ-ray (253 keV) one finds the exact energy values of three transitions found in the singles spectrum, which, then, have to be cross-overs (namely 1427, 1748 and 1838 keV leading to levels at 1680, 2001, 2091 keV respectively).

According to Panar's work, the intrinsic state $5/2^+$ [402] has an energy of 254 keV. It is, therefore, appealing to decide that we are dealing with the same state at 253 keV. We will come back later to this question.

4.4. The $1/2^-$ [541] band

Table 2 shows that the 1355 keV peak is in coincidence with both the 211 and 218 keV γ-rays. Since the energy difference between these two peaks is 7 keV (which is the spacing between the energy levels 217.7 and 205.9 keV) one could consider these two transitions as depopulating the same 424.3 keV level to the $3/2^+$ and $1/2^+$ of the $1/2^+$ [411] state respectively. From our experiments we are able to decide that the 211.5 keV radiation is an E1 transition. In such a case, this 424.3 keV would be a good candidate for the $1/2^-$ [541] state expected in this region. It would have been more convincing of course, if the 218.4 keV transition was known to have the E1 multipole order. Unfortunately, a very strong 217.7 keV transition in the daughter contaminates it. Moreover, in the conversion electron spectrum the K-line of the 217.7 keV transition is mixed with the L-line of the 173.1 keV transition in ^{159}Dy. Such an assignment disagrees with the proposals of Gromov et al [6] and Adam et al [12] but is in perfect agreement with Panar's results, who locates the $1/2^-$ [541] at 425 keV. They also found the $5/2^-$ rotational state of this band at 464 keV. Our 1355.3 keV E2 transition found in coincidence with the 211.5 and 218.4 keV γ-rays leads to a 1779.5 keV level, from which a 1316.3 keV γ-ray feeds this $5/2^-$ rotational level.

4.5. The $5/2^+$ [413] state

By combining coincidence results and arithmetical considerations, a level may be located at 671.6 keV since the 165.9 and 252.9 keV transitions are in coincidence respectively with the 505.7 keV and 418.7 γ-rays. The 505.7 keV M1 transition would feed the $7/2^+$ [404] state and the 671.6 keV state decays to the 252.9 keV level through an (M1 + E2) transition. The level must then have an even parity, which is consistent with its log ft value of 7.0. This indicates a first forbidden transition implying a parity change between the parent ground state ($I^\pi = 3/2^-$) and the 671.6 keV level. The $5/2^+$ [413] state is the only available candidate, all the more so as in the $^{161-165}$Ho isotopes it appears at energies of the same order of magnitude (fig. 3).

4.6. Levels at 580.7 - 624.2 and 649.1 keV

The intensities of the 624.2 and 649.1 keV transitions (respectively 29 and 20% of the total decay) are such that the existence of two levels at 624.2 and 649.1 keV cannot be called into question. With regard to the 580.7 keV transition, although it is weaker than the other two (roughly 3.5 %) it would be difficult not to admit that it is connecting a level at 580.7 keV to the ground state. A clear coincidence of this γ-ray with some higher energy γ-rays has been observed. For example the coincidence between this γ-ray and the 498.7 keV transition supports the existence of a level at 1779.5 keV from which four other γ-rays (1316.3-1355.3-1466.7 and 1566.9 keV) depopulate respectively to the 463.3-424.3-312.8 and 212.7 keV levels. Incidentally, it would not be illogical to find in this argument one more piece of evidence for confirming the reality of these low-lying levels already discussed.

The knowledge of the multipole order of the three strong γ-rays allows us to assign the spins and parities of these three levels. But they are difficulties in determining the corresponding Nilsson states. According to the systematics in $^{161-163-165}$Ho, the γ-vibrational (K-2) band head built on the $7/2^-$ [523] ground state is expected in the range of 500-600 keV (fig. 3). Very likely the 580.7 keV level is explained in this way since the 580.7 keV γ-ray is an E2 transition. As in ^{161}Ho [15, 16] this vibrational level is strongly populated by transitions coming from high energy levels.

As to the 624.2 and 649.1 keV levels the multipole order of the transitions and the log ft values require the spin 5/2 and the parity π^- for these levels. The only $5/2^-$ states available in this energy range are the $5/2^-$ [532] state and the $5/2^-$ rotational state of the $3/2^-$ γ-vibrational state that we located at 580.7 keV. Assuming that the 624.2 keV level is this $5/2^-$ rotational state, the apparent moment of inertia parameter would then have the value 8.7 keV. If we suppose that the 649.1 keV level fulfils this rôle, the moment of inertia parameter would have the value 13.7 keV. Now, a systematics of the moment of inertia parameter of this vibrational band in ^{161,163,165}Ho, shows that it has the respective values 11.3 - 11.6 and 10.1 keV, so that in comparing ^{159}Ho to the other isotopes, the $\hbar^2/2J$ value would be either too large or too small. This discrepancy can be explained by the existence of two levels, having the same spin and parity and close in energy, which mutually repel each other. The unpertubed $5/2^-$ level of the $3/2^-$ γ-vibrational band should be located somewhere between 624 and 649 keV and would have a rotational parameter of the order of magnitude of that given by the systematics. Moreover, the two $5/2^-$ states are strongly mixed and their wave function may be written.

$$\psi = \phi_o + \sum_n C_n \phi_n$$

where C_n is the mixing coefficient and ϕ_o the wave function of the unpertubed state. To the first order C_n can be written

$$C_n = \frac{\langle \phi_n | C | \phi_o \rangle}{|E_o - E_n|}$$

where $|E_o - E_n|$ represents the energy spacing between the two levels. C_n has a large value either for a large matrix element of for a small energy difference between the two levels. We are dealing with the second possibility since the unpertubed states lie close in energy although they have a sm... interaction matrix element. One may presume that both

states have components of the same order of magnitude in the two unpertubed states. This would explain the observation of the two strong M1 transitions. Such an hypothesis is confirmed by the fact that in ^{161}Ho [15, 16] and ^{157}Ho [18] in which the two $5/2^-$ states have a larger energy spacing, no mixing has been found and only one strong M1 transition has been observed, namely the $5/2^-$ [532] to $7/2^-$ [523] transition.
It is worthwhile to point out that the 649.1 keV level decays by a M1 transition to the ground state and by a 551.6 keV E2 transition to the first rotational state $9/2^-$ of the $7/2^-$ [523] band. From these considerations we may assume that the component of the vibrational level prevails in the 649.1 keV level.

4.7. Level at 815.6 keV

This level is mainly determined by a coincidence between the 562.7 γ-ray and the 252.9 keV γ-ray. The large log ft value (7.4) entails for this level, a positive parity which is confirmed by the E2 or E2 + M1 multipole order of the 562.7 keV transition, so that its spin could be either $1/2^+$ or $3/2^+$. One could think of the intrinsic level $K^\pi = 1/2^+$ of the vibrational (K-2) band based on the $5/2^+$ [402] level.
In their experiments Panar et al [7] determined a level at 815 keV which is assumed to be the $K^\pi = 3/2^+$ vibrational level based on the $7/2^+$ [404] band. In such a case an E2 transition should be observed between the 815.6 keV level and the 165.9 keV level. Moreover, a coincidence has been found between the 649.1 keV γ-ray and the 165.9 keV γ-ray : one of these two γ-rays has to be composite and there is no way to decide whether one of the two 165.5 keV γ-transitions is in coincidence with a unique 649.1 keV γ-ray. We cannot draw any conclusion, all the more as the $K^\pi = 3/2^+$ vibrational level based on the $1/2^+$ [411] state could be a third candidate.

4.8. High energy levels

Based on both coincidence results and arithmetical considerations, the determination of the energy and parity of thirteen high energy levels has been possible and one may assign plausible spin value to eleven of them from the knowledge of multipole order of some transitions. It would be rash to try to give a conclusive interpretation of these levels but we may suggest some likely proposals :

i) The 1468.1 and 1492.8 keV levels could be the $3/2^-$ [541] and $3/2^-$ [532] states expected, in this region, at an energy greater than 1 MeV. The calculations of SOLOVIEV et al [19] predict the $3/2^-$ [541] level at 1420 keV. The 1558.5 level, whose spin is $5/2^-$, should then be the first rotational level of one of these bands.

ii) The 1779.5 keV level which feeds the $1/2^-$ [541] intrinsic state by means of a strong 1355.2 keV E2 transition could be the intrinsic level of the (K-2) vibrational band based on the $1/2^-$ [541] state, all the more as, from this 1779.5 keV level, two γ-transitions populate the $3/2^-$ and $5/2^-$ rotational states of the $1/2^-$ [541] band.

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TABLE 1

Energies and intensities of the transitions in ^{159}Ho

E_γ	I_K	I_γ	$10^3\,\alpha_K$ (exp)	Multipolarity	Total intensity	I_{tot}/1000 decays	Assignment
97.5	68.5	23	$\alpha_L = 0.5086$	M1+E2	106	30.0	97.5 → 0
106.9	32.1	12	$\alpha_L = 0.4492$	E2	50	14.1	312.8 → 205.9
131.9							^{159}Dy
132.1		≃ 10			≃ 10	≃ 2.8	298.0 → 165.9
165.5		< 10			< 10	< 2.8	815.6 → 649.1
165.9	8.9	150	59	E1	161	45.5	165.9 → 0
205.9	143	290	493	E3	605	171	205.9 → 0
211.5	2.0	35	57	E1	37	10.5	424.3 → 212.7
217.7							^{159}Dy
218.4		≃ 28			≃ 28	≃ 8.8	424.3 → 205.9
252.9		≃ 100			≃ 100	≃ 28.3	^{159}Dy and 252.9 → 0
307.6		10			10	2.8	(520.3 → 212.7)
314.4		35			35	9.9	520.3 → 205.9
366.4		6.6			6.6	1.9	
370.0		4.4			4.4	1.3	
391.3	0.13	13	10	E1	13	3.6	815.6 → 424.3
418.7	0.19	5.4	35	M1 or E 2	5.6	1.6	671.6 → 252.9
436.4	0.029	7.4	3.9	E1	7.5	2.1	649.1 → 212.7
482.7	0.19	4.6	26	M1	4.8	1.4	
505.7	1.5	55	28	M1	57	15.7	671.6 → 165.9
551.6	0.81	70	12	E2	71	20.1	649.1 → 97.5
562.7	0.136	9.7	14	E2	9.9	2.8	815.6 → 252.9
580.7	1.16	121	9.6	E2	123	34.8	580.7 → 0
599.0	0.187	8.2	23	M1	8.4	2.4	
610.2		6.0			6.0	1.7	
613.4		4.8			4.8	1.4	
624.2	15.8	1000	15.8	M1	1019	288	624.2 → 0

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E_{γ}	I_K	I_{γ}	$10^3.\alpha_K$(exp)	Multipo-larity	Total intensity	I_{tot}/ decays	Assignment
649.1	10.1	700	14.2	M1	712	201	649.1 → 0
668.1		7.2			7.2	2.0	
774.1	0.047	5.5	8.5	M1	5.6	1.6	(1355.1 → 580.7)
817.6	0.034	7.7	4.4	M1 or E2	7.8	2.2	1398.3 → 580.7
843.9	0.136	21		M1 or E2	21	5.9	1468.1 → 624.2
851.4	0.132	23			23		$^{159}Dy + ^{159}Ho$
887.4		15			15	4.2	1468.1 → 580.7
918.8		3.4			3.4	0.96	
942.2	0.071	32	2.2	E1 or E2	32	9.1	
947.3	0.017	4.5	3.7	M1 or E2	4.5	1.3	
964.8	0.052	9.2	5.8	M1	9.3	2.6	
972.5	0.033	4.5	7.3	M1	4.6	1.3	1492.8 → 520.3
987.8	0.034	5.9	5.9	M1	6.0	1.7	
1046.5		5.7			5.7	1.6	
1052.0		3.4			3.4	0.96	
1078.6		2.9			2.9	0.82	
1086.7		2.8			2.8	0.79	
1103.0		5.6			5.6	1.6	
1110.1		4.7			4.7	1.3	
1119.9		4.2			4.2	1.2	
1125.6		3.3			3.3	0.93	
1137.6		6.0			6.0	2.0	
1152.4		5.9			5.9	1.7	
1185.8		8.3			8.3	2.3	
1189.2	0.024	6.4	3.7	M1	6.5	1.8	1355.1 → 165.9
1198.8	0.079	25.	3.2	M1	26	7.2	1779.5 → 580.7
1209.5		13			13	3.6	
1219.8		6.2			6.2	1.8	
1224.5		4.4			4.4	1.2	

.../...

E_γ	I_K	I_γ	$10^3.\alpha_K$(exp)	Multipolarity	Total intensity	I_{tot} /1000 decays	Assigment
1226.1	0.013	8.8	1.5	E2 or E1	8.8	2.5	1689.4 → 463.3
1231.1	0.0064	11	0.6	(E1)	11	3.1	1902.7 → 671.6
1232.4	0.0064	16	0.4	(E1)	16	4.6	1398.3 → 165.9
1239.9	0.013	18	0.7	(E1)	18	5.2	1492.8 → 252.9
1255.7		5.5			5.5	1.6	1680.0 → 424.3 und (1468.1 → 212.7)
1285.3		5.7			5.7	1.6	
1291.4		6.3			6.3	1.8	
1295.4		3.5			3.5	1.0	
1316.2		4.6			4.6	1.3	1779.5 → 463.3
1329.1		8.6		(E1)	8.6	2.4	1495.0 → 165.9
1334.9		7.8			7.8	2.2	
1355.2	0.043	29	1.5	E2	29	8.1	1779.5 → 424.3 and 1355.1 → 0
1365.3		4.7			4.7	1.3	
1392.6		17		(E1)	17	4.8	1558.5 → 165.9
1402.4	0.018	8.7	2.1	M1 or E2	8.7	2.5	
1418.1		4.7			4.7	1.3	
1427.1	0.018	23	0.8	E1 or E2	23	6.4	1680.0 → 252.9
1443.3		5.0			5.0	1.4	
1445.8		6.2			6.2	1.8	
1459.2		9.8			9.8	2.8	
1466.7	0.007	7.8	9.4	E1 or E2	7.8	2.2	1779.5 → 312.8
1476.7		5.8			5.8	1.6	1689.4 → 212.7
1495.0		4.0			4.0	1.1	1495.0 → 0
1523.5	0.011	4.4	2.5	M1	4.4	1.2	1689.4 → 165.9
1552.9		28		(E1)	28	8.0	
1558.5	0.014	14	1.0	M1 or E2	14	3.8	1558.5 → 0
1566.9		8.1			8.1	2.3	1779.5 → 212.7
1594.8		4.2			4.2	1.2	

.../...

E_γ	I_K	I_γ	$10^3.\alpha_K$(exp)	Multipolarity.	Total intensity	I_{tot}/1000 decays	Assignment
1598.5	0.070	7.9	0.9	E2	7.9	2.2	
1618.1		3.8			3.8	1.1	
1631.8		10			10	2.8	
1652.7		3.7			3.7	1.1	
1658.7		5.1			5.1	1.4	
1679.3		2.2			2.2	0.6	1891.0 → 212.7
1680.0		4.4			4.4	1.2	1680.0 → 0
1685.1		3.8			3.8	1.1	1891.0 → 205.9
1708.3		3.9			3.9	1.1	
1748.7		3.6			3.6	1.1	2001.6 → 252.9
1775.2		7.3			7.3	2.1	
1786.0		5.1			5.1	1.4	
1792.2		3.6			3.6	1.0	
1838.8	0.011	37	0.3	(E1)	37	10	2091.7 → 252.9
1891.0	0.015	31.	0.5	E1 or E2	31	8.8	1891.0 → 0
1906.2		3.9			3.9	1. 1	
2001.6	0.0066	29	0.23	(E1)	8.1	2.3	2001.6 → 0
2006.4	0.01	15	0.7	E2	15	4.1	
2038.1		6.3			6.3	1.8	
2091.7		8.6			8.6	2.4	2091.7 → 0

In column 1 the γ-ray energies are given with an error of the order of ± 0.3 keV.

In column 2 the K-conversion intensities were normalized for an E3 assignment at 205.9 keV. The errors are of the order of 10 à 25% depending on the line strength. For the 97.5 keV and 106.9 keV lines, the intensities are calculated values. Some L- conversion intensities are experimentally known

E_γ	I_L	E_γ	I_L
97.5	11.7	551.6	0.12
106.9	5.3	624.2	2.2
165.9	8.9	649.1	1.6
205.9	167		

In column 3 the γ-ray intensities are given with an error of 10 to 30% depending on the line strength.

In column 4, for the 97.5 and 105.9 keV lines only the experimental L-conversion coefficients are given. Errors on α_K coefficients may come up to 50%.

TABLE 2 - γ-γ coincidences measured in the ^{159}Er decay

$E_{\gamma 1}$	$E_{\gamma 2}$ [a]
97	551
132[b]	166, (253)
166[b]	132, 218[b], 506, (649), 1189, 1232, 1329, 1335[c] 1392, 1523
211	1355
218[b]	1355
253[b]	89[c] 130[c] (307), 418, 563, 1240, 1427, 1748, 1838
483[c]	166
506	166, (624)[c], 1231
552,	89[c] 97,
563	253
581	(130)[c] 817, 851[b)c)], 887, 1199
599	97[c]
624	511 (843)
649	166, 511
817	166, 580
851[b]	166[c]
1086	(166)[c] (506)[c]
1186	(166)[c] (253)[c]
1189	(166)
1199	581
1232	166
1240	253
1329	(166)
1355	211, 218[b]
1392	166
1838	253

a) coincidences given in parentheses are weak or uncertain

b) This line is composite (^{159}Dy + ^{159}Ho)

c) This coincidence is not introduced in the Level scheme.

FIGURE CAPTIONS

Fig. 1.a - Partial γ-ray spectrum from the decay of ^{159}Er.

Fig. 1.b - Partial γ-ray spectrum from the decay of ^{159}Er.

Fig. 2.a - Part of the conversion-electron spectrum measured with Si(Li) detector.

Fig. 2.b - Part of the conversion-electron spectrum measured with Si(Li) detector.

Fig. 3. - Experimentally observed Nilsson simple-quasiparticle states and bandhead of the γ-vibrational band based on the ground state in the odd A $^{157-165}Ho$ isotopes. These date were obtained from the following references : ^{157}Ho [7,18] , ^{159}Ho [7] and present work, ^{161}Ho [7, 15, 16], ^{163}Ho [7,20,22], ^{165}Ho [17,20] .

Fig. 4. - Level scheme of ^{159}Ho.

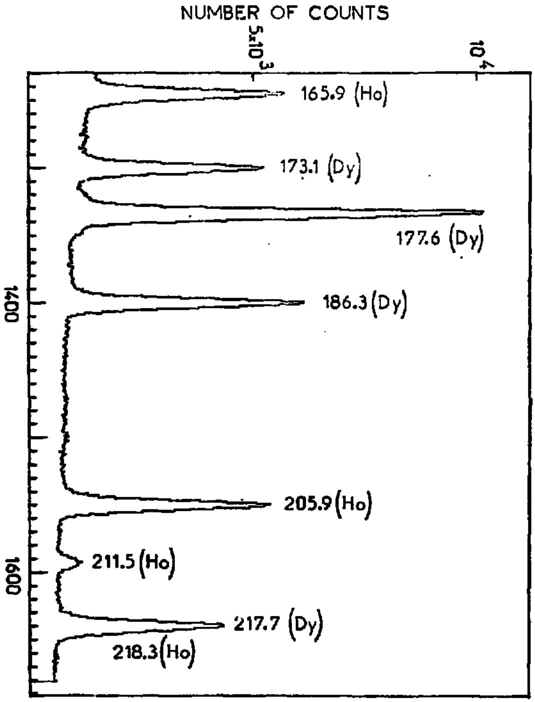

NUMBER OF COUNTS
5x10^3
10^4
1400
1600
165.9 (Ho)
173.1 (Dy)
177.6 (Dy)
186.3 (Dy)
205.9 (Ho)
211.5 (Ho)
217.7 (Dy)
218.3 (Ho)

Fig 1.2

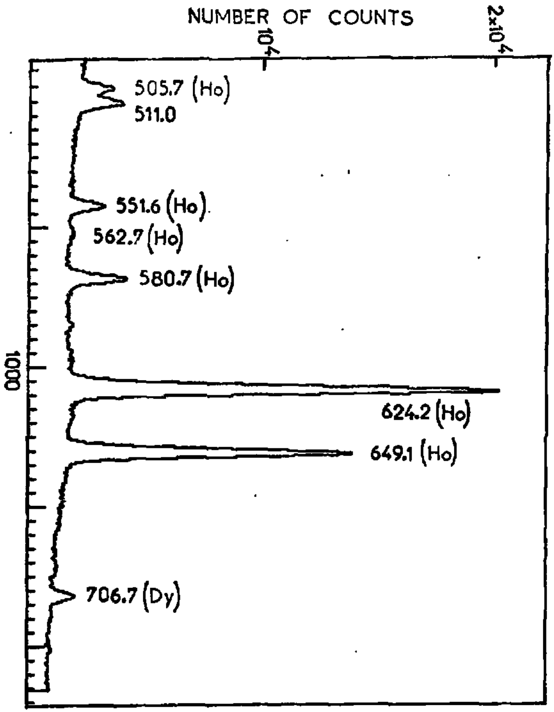
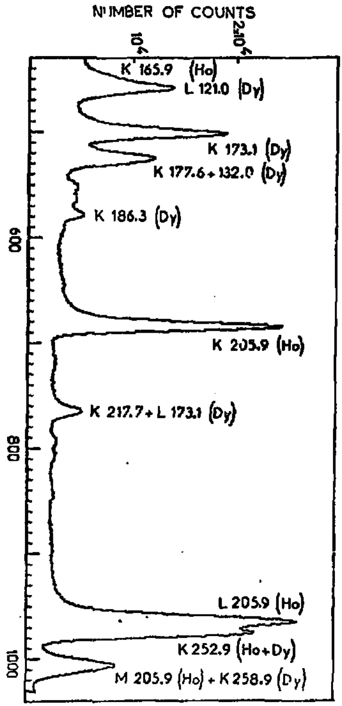
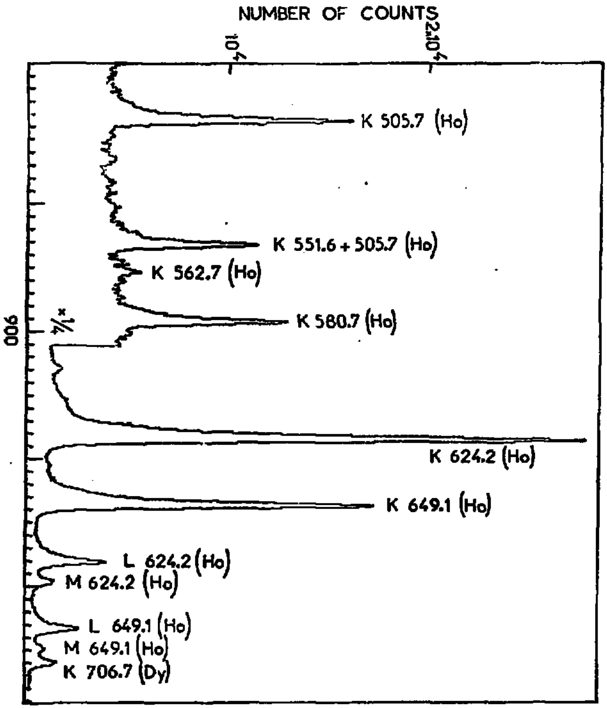

NUMBER OF COUNTS
10⁴
2x10⁴
1000
505.7 (Ho)
511.0
551.6 (Ho)
562.7 (Ho)
580.7 (Ho)
624.2 (Ho)
649.1 (Ho)
706.7 (Dy)

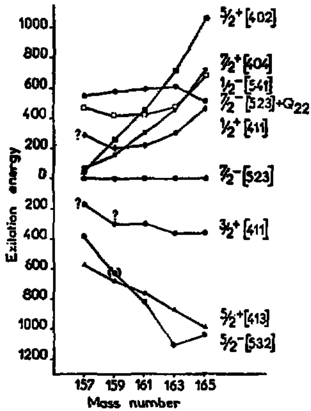
Fig 4.6



NUMBER OF COUNTS
10⁴
2x10⁴
K 165.9 (Ho)
L 121.0 (Dy)
K 173.1 (Dy)
K 177.6 + 132.0 (Dy)
K 186.3 (Dy)
600
K 205.9 (Ho)
K 217.7 + L 173.1 (Dy)
800
L 205.9 (Ho)
K 252.9 (Ho+Dy)
1000
M 205.9 (Ho) + K 258.9 (Dy)



NUMBER OF COUNTS
10^4
2.10^4
900
x 1/4
K 505.7 (Ho)
K 551.6 + 505.7 (Ho)
K 562.7 (Ho)
K 580.7 (Ho)
K 624.2 (Ho)
K 649.1 (Ho)
L 624.2 (Ho)
M 624.2 (Ho)
L 649.1 (Ho)
M 649.1 (Ho)
K 706.7 (Dy)



1000
800
600
400
200
0
200
400
600
800
1000
1200
Exitation energy
157 159 161 163 165
Mass number
5/2+ [402]
7/2+ [404]
1/2− [541]
7/2− [523]+Q22
1/2+ [411]
7/2− [523]
3/2+ [411]
5/2+ [413]
5/2− [532]

Fig. 3

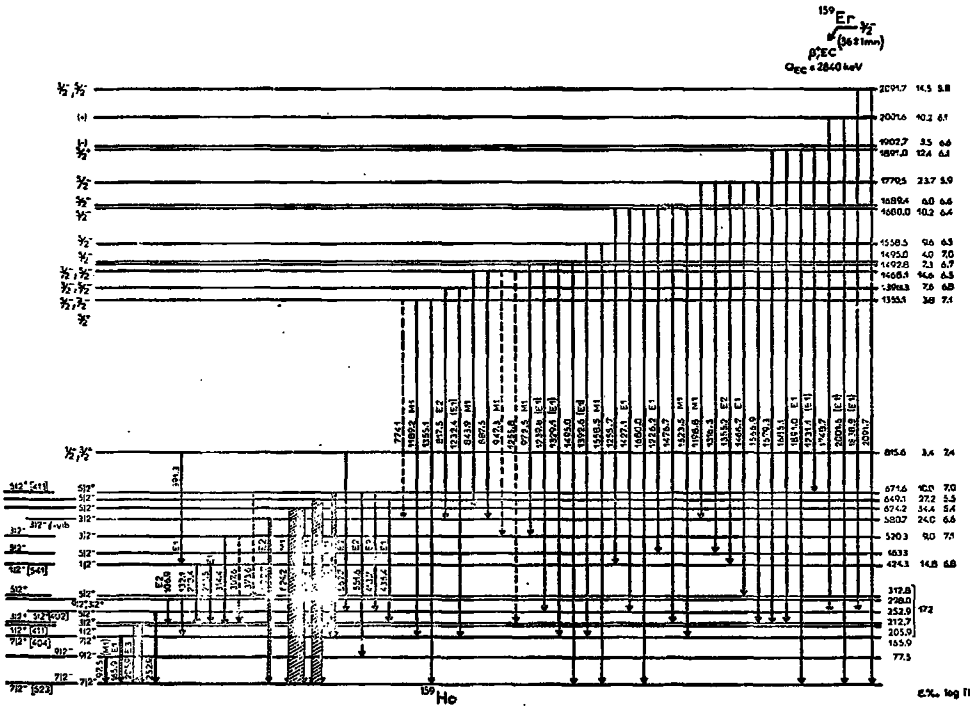


Fig. 4