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ISOMERIC STATE AND ROTATIONAL BAND IN ^{158}Ho

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Résumé. — Le noyau impair-impair ^{158}Ho a été étudié au moyen des réactions $^{159}\text{Tb}(\alpha, 5n)^{158}\text{Ho}$ et $^{160}\text{Dy}(p, 3n)^{158}\text{Ho}$. Un état isomérique de période $T_{1/2} = (29 \pm 3)$ ns a été mis en évidence. Une bande de rotation a été développée jusqu'au spin 16^- .

Abstract. — The odd-odd ^{158}Ho nucleus is studied by means of the reactions $^{159}\text{Tb}(\alpha, 5n)^{158}\text{Ho}$ and $^{160}\text{Dy}(p, 3n)^{158}\text{Ho}$. The life-time of an isomeric state is measured as $T_{1/2} = (29 \pm 3)$ ns. A rotational band is developed up to spin 16^- .

1. **Introduction.** — In the framework of a systematic study of the spectroscopy of neutron-deficient holmium isotopes, the level scheme of the odd-odd nucleus ^{158}Ho has been investigated.

A previous investigation by Stenström and Jung [1] determined the genetic relationships and half-lives of ^{158}Ho isomers. Recently Abdurazakov *et al.* [2] and Harmatz and Handley [3] have investigated the decay scheme of the nucleus $^{158}\text{Er} \rightarrow ^{158}\text{Ho}$. As a result of their investigations the ground state of ^{158}Ho is found to have spin and parity 5^+ corresponding to 67 protons and 91 neutrons with a $p\ 7/2^- [523] \uparrow n\ 3/2^- [521] \uparrow$ configuration. An isomeric state ($T_{1/2} = 27$ min.) in ^{158}Ho with energy 67.3 keV is known which has been interpreted as having spin and parity 2^- and which corresponds to possible configurations :

$p\ 1/2^+ [411] \downarrow n\ 5/2^- [523] \downarrow$ Ref. [2]
 $p\ 7/2^+ [404] \downarrow n\ 3/2^- [521] \uparrow$ Ref. [3]
 $p\ 7/2^- [523] \uparrow n\ 3/2^+ [402] \downarrow$

It is the purpose of this letter to discuss the above possibilities and compare them with our data which concern the levels of ^{158}Ho studied by in beam spectroscopic methods in the reactions $(\alpha, xn\gamma)$ and $(p, xn\gamma)$.

2. **Experimental procedure and results.** — The in beam experiments were carried out at the Grenoble cyclotron. For the $^{159}\text{Tb}(\alpha, 5n)$ reaction, a mono-isotopic terbium foil target of 5 mg/cm² was used. The $^{160}\text{Dy}(p, 3n)$ reaction was performed with a 5.5 mg/cm² 85 % enriched $^{160}\text{Dy}_2\text{O}_3$ target. The

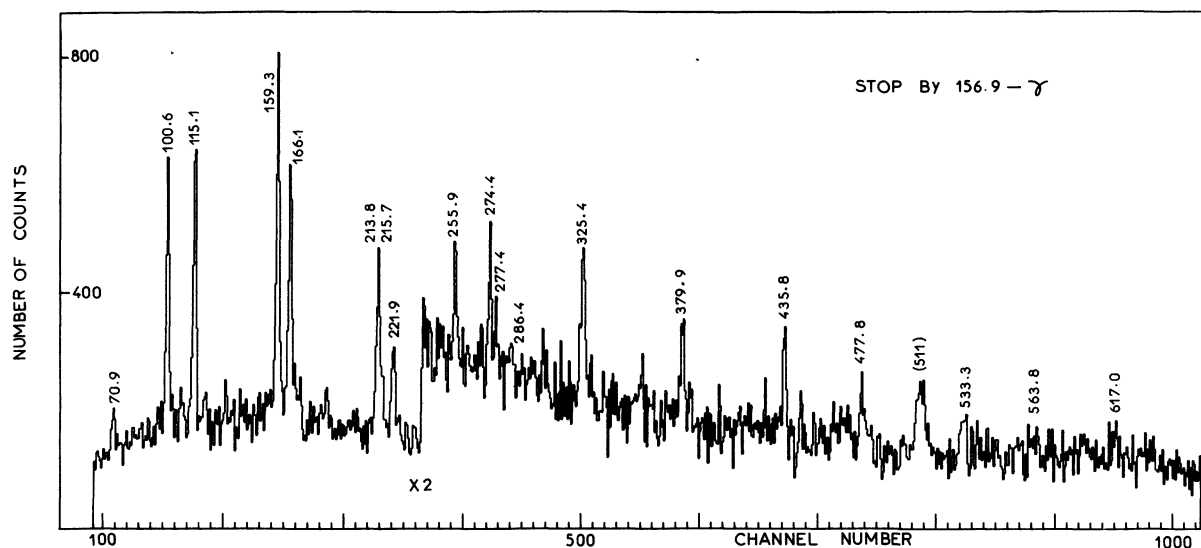
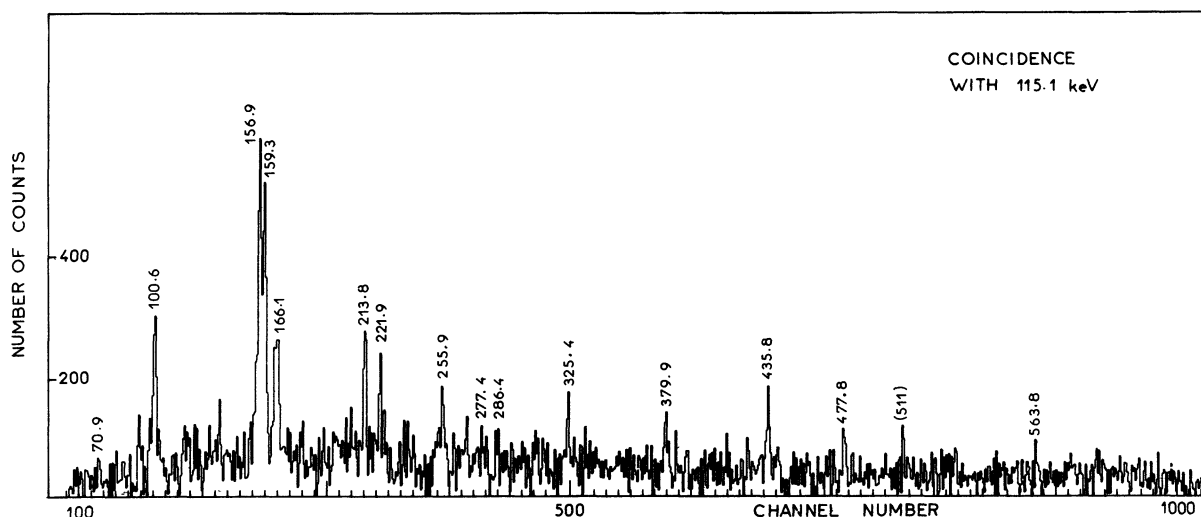
study of excitation functions suggested that alpha and proton particle energies of approximately 63 MeV and 43 MeV respectively were the most favourable for the production of ^{158}Ho . Gamma lines belonging to

TABLE I

Summary of the experimental results

E_γ	I_γ	Assignment
67.3 ± 0.1	95 ± 8	^{158}Ho $2^- \rightarrow 5^+$
70.9 ± 0.1	72 ± 6	^{158}Ho $6^- \rightarrow 5^-$
98.9 ± 0.1	540 ± 50	^{158}Dy
100.6 ± 0.2	185 ± 19	^{158}Ho $7^- \rightarrow 6^-$
115.1 ± 0.2	200 ± 20	^{158}Ho $8^- \rightarrow 7^-$
156.9 ± 0.1	1 000 ± 90	^{158m}Ho $5^- \rightarrow 5^+$
159.3 ± 0.2	210 ± 21	^{158}Ho $9^- \rightarrow 8^-$
166.1 ± 0.1	250 ± 26	^{158}Ho $10^- \rightarrow 9^-$
171.5 ± 0.3	w	^{159}Ho
213.8 ± 0.2	155 ± 16	^{158}Ho $7^- \rightarrow 5^-$
215.7 ± 0.2	163 ± 17	^{158}Ho $11^- \rightarrow 10^-$
218.2 ± 0.1	1 320 ± 80	^{158}Dy
221.9 ± 0.2	89 ± 12	^{158}Ho $8^- \rightarrow 6^-$
255.9 ± 0.3	55 ± 7	^{158}Ho $12^- \rightarrow 11^-$
274.4 ± 0.3	77 ± 8	^{158}Ho $13^- \rightarrow 12^-$
277.4 ± 0.4	35 ± 12	^{158}Ho $9^- \rightarrow 7^-$
286.4 ± 0.4	35 ± 12	^{158}Ho $14^- \rightarrow 13^-$
320.4 ± 0.1	850 ± 80	^{158}Ho $15^- \rightarrow 14^-$
325.4 ± 0.2	210 ± 21	^{158}Dy
379.9 ± 0.2	163 ± 18	^{158}Ho $10^- \rightarrow 8^-$
425.4 ± 0.2	50 ± 5	^{158}Ho $11^- \rightarrow 9^-$
435.8 ± 0.2	246 ± 25	^{158}Dy
477.8 ± 0.2	107 ± 13	^{158}Ho $12^- \rightarrow 10^-$
533.3 ± 0.2	155 ± 16	^{158}Ho $13^- \rightarrow 11^-$
563.8 ± 0.3	134 ± 20	^{158}Ho $14^- \rightarrow 12^-$
617.0 ± 0.3	100 ± 12	^{158}Ho $15^- \rightarrow 13^-$
		^{158}Ho $16^- \rightarrow 14^-$

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FIG. 1. — Example of coincident spectrum (stop by 156.9 keV- γ).FIG. 2. — Example of coincident spectrum (115.1 keV- γ).

^{157}Ho and ^{159}Ho and their daughter products were observed in the spectrum due to the (α , 6n) and (α , 4n) reactions.

The experimental information consists of γ -ray spectra (in and out of beam), the life-time of the isomeric state measured using the cyclotron pulses and the prompt and delayed γ - γ coincidences. The results of our experiments are summarized in table I and in figures 1, 2, 3 and 4. In table I only the energies and the relative γ -ray intensities for the lines of ^{158}Ho and ^{158}Dy are tabulated. A spectrum obtained using the delayed coincidence method is presented in figure 1. In this figure the 156.9 keV γ -ray is taken as the gate STOP. Figure 2 gives an example of the prompt coincidences for the 115.1 keV γ -ray. The decay curve for the 156.9 keV line of ^{158}Ho is shown in figure 3.

3. Data analysis and results. — In the course of measurement of in and out of beam gamma spectra, an intense delayed gamma line at 156.9 keV was found to decay with a half-life of (29 ± 3) ns. A comparison of this value with those assigned for the isomeric states in odd-odd holmium isotopes is given in the following table.

	^{164}Ho [4]	^{162}Ho [5, 6]	^{160}Ho [5]	^{158}Ho
Spin	6^-	6^-	(5^-)	6^-
$T_{1/2}$	37.5 min.	68 min.	60 ns	29 ns
Energy	139 keV	106 keV	118.1 keV	156.9 keV

Thus, while both the ^{162}Ho and ^{164}Ho nuclei seem to have a 6^- isomeric state with the

$$p \ 7/2^- \ [523] \uparrow \ n \ 5/2^+ \ [642] \uparrow$$

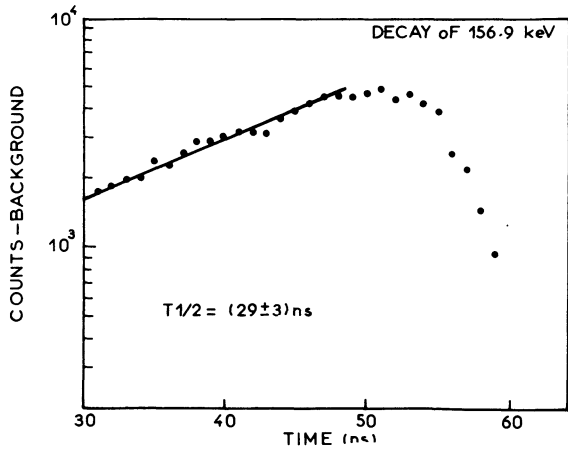


FIG. 3. — The decay of the 156.9 keV peak.

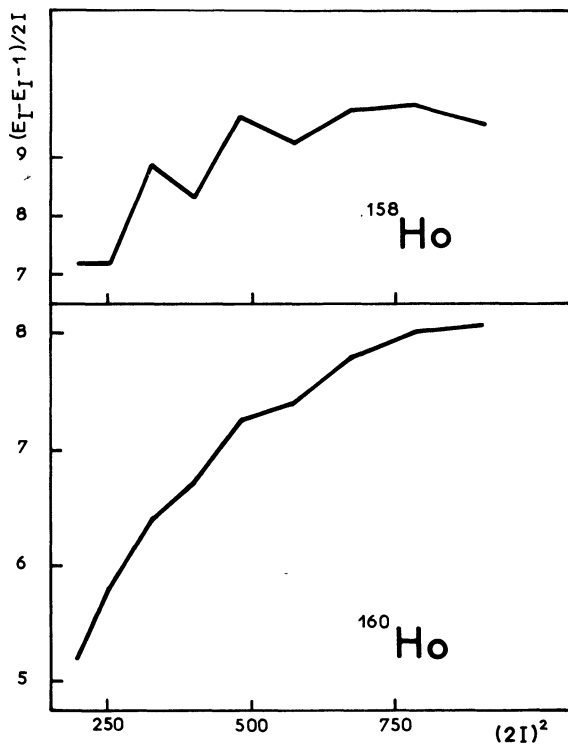


FIG. 4. — Plot of effective inverse moments-of-inertia associated with individual cascade transitions for ^{158}Ho and ^{160}Ho .

configuration, the isomeric state observed at 118.1 keV in ^{160}Ho apparently has not this configuration as reported by Leigh, Stephens and Diamond [5]. These authors indicated that the 6^- state should also occur in ^{160}Ho and the rotational band observed is probably based on this state with the configuration $6^-, p 7/2^- [523] \uparrow n 5/2^+ [642] \uparrow$. This conclusion was based on the very great similarity between the sequence of γ -rays transitions in both ^{162}Ho and ^{160}Ho . Moreover the oscillations in the energy level spacings for ^{162}Ho and ^{160}Ho obtained by plotting

$$(E_I - E_{I-1})/2I \text{ vs } f(2I)^2$$

are in phase. The isomeric state could be a 5^- state with the configuration $p 7/2^- [523] \uparrow n 3/2^+ [402] \downarrow$.

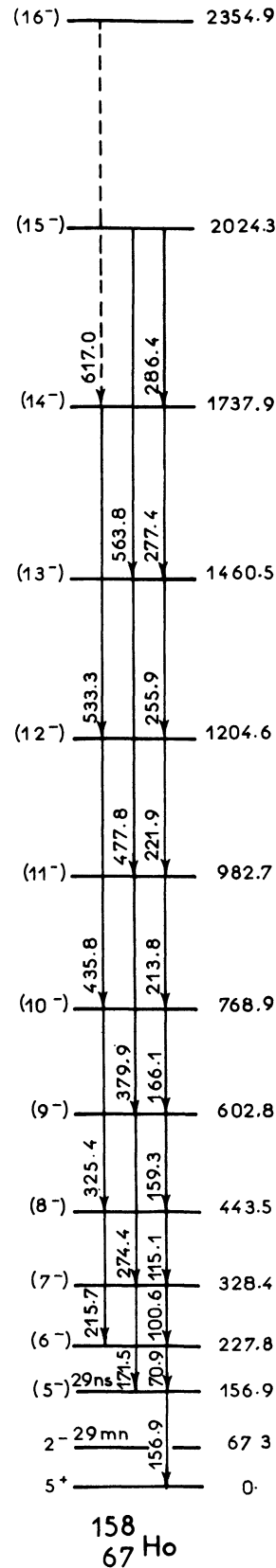


FIG. 5. — Proposed level scheme of ^{158}Ho .

With regard to the nucleus ^{158}Ho , it must be noted that the sequence of γ -transition is different from that in ^{160}Ho . This discrepancy may be explained by the presence of the $p 7/2^- [523]$ Nilsson level in the

configuration which shows strong perturbation by Coriolis coupling. The increasing perturbation of the p $7/2^-$ [523] band with decreasing mass number is indicated by the variation of the strength of fluctuations in neighbouring ^{157}Ho and ^{159}Ho nuclei [7]. Figure 4 shows this in a plot of $f(2I)^2$ for ^{160}Ho and ^{158}Ho . It is clear that the perturbation in the energy level spacing of ^{158}Ho is stronger than that in ^{160}Ho . If we suppose that the curves $(E_I - E_{I-1})/2I$ must be in phase in both ^{160}Ho and ^{158}Ho , the 156.9 keV state of spin 5^- must be assigned as the isomeric state in the ^{158}Ho nucleus. The spin $I = K = 6^-$ might be attributed to the head of the rotational band.

However, two other assumptions are also possible :

1) The 6^- state could be attributed as the isomeric state and considered as the head of the rotational band.

2) The isomeric state could be assigned as the 5^- state by supposing a weak transition between the 6^- and 5^- state. We could not see a gamma line of such low energy with our experimental arrangement; if present, it is undoubtedly highly converted and will be difficult to observe. In this case the γ -ray

of 72.9 keV could represent the transition between the 7^- and 6^- states.

By choosing the spin and parity of the isomeric state as 5^- , a possible configuration for this state is p $7/2^-$ [523] \uparrow n $3/2^+$ [402] \downarrow . According to Gallagher-Moszkowski's rule, the 2^- state of 67.3 keV in ^{158}Ho is the lower member of the doublet. However, this situation leads to a different interpretation from that given in refs. [2, 3].

4. Conclusion. — a) The level scheme of ^{158}Ho proposed on the basis of our experiments is shown in figure 5.

b) The rotational band observed in ^{158}Ho is highly perturbed by Coriolis coupling. This is due to the fact that the orbits of the proton and neutron states originate from high- j shells of $h_{11/2}$ and $i_{13/2}$ respectively and to the fact that with decreasing A the perturbation increases rapidly in the neighbouring odd- A nuclei.

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