LEVELS IN ^{158}Dy AS POPULATED FROM DECAY
OF ^{158}Ho IN EQUILIBRIUM WITH 2.3-h ^{158}Er

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Abstract: The γ -ray spectrum of the decay of ^{158}Ho in transient equilibrium with 2.3-h ^{158}Er has been studied with Ge(Li) detectors. Results of γ -ray singles and coincidence experiments are reported and a decay scheme for $^{158}\text{Ho} \rightarrow ^{158}\text{Dy}$ is proposed. New levels have been assigned to the β -vibrational band and a rotational band built on the two-quasineutron state (ν $5/2^-$ [523] + ν $3/2^-$ [521]). A new $K=2$ rotational band with spins up to 6^+ built on a level at 1851.9 keV is proposed. An attempt is made to characterize a group of negative parity states at about 1400 keV and tentative assignments of the $K = 0, 1$ and 2 octupole vibrational band heads are suggested.

RADIOACTIVITY ^{158}Ho [from ^{148}Nd ($^{14}\text{N}, 4n$); ^{150}Sm ($^{12}\text{C}, 4n$) ^{158}Er , ^{151}Eu ($^{11}\text{B}, 4n$) ^{158}Er (2.3-h, EC, β^+) ^{158}Ho]; measured E_γ , I_γ , $\gamma\gamma$ coin, $T_{1/2}$, deduced $\log ft$, ^{158}Dy deduced levels, J , π , α_K , γ -multipolarities. Ge(Li) detectors.

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1. Introduction

In recent years it has proved interesting to look back with care at the decay schemes of nuclides where a great deal of information is available but where some expectations of the theory are as yet unfulfilled or perhaps poorly characterized. Thus, in the course of investigating the decay of 2.3-h ^{158}Er which populates levels in ^{158}Ho , we also acquired information about the decay of the 0.5-h $^{158\text{m}}\text{Ho}$ and 10.9-m $^{158\text{g}}\text{Ho}$ in transient equilibrium with ^{158}Er . The level scheme deduced from these γ -ray data taken with Ge(Li) detectors together with the results of other groups, is the subject of this paper.

The most recent study of the ^{158}Dy level scheme as populated in radioactive decay is that of Abdurazakov et al.¹⁾ They measured the energies of β -rays and conversion electrons following the decay of ^{158}Ho using a β -ray spectrometer and established the Q-value (4220 keV). Their level scheme for ^{158}Dy includes the ground state band (up to I=6), a γ -vibrational band (up to I=7), the first two members of a β -vibrational band, a two-quasiparticle state and several negative parity states. Other recent work includes the ^{158}Dy level scheme as populated in-beam with (p,2n) and (d,3n) reactions by Jett and Lind²⁾ and as populated by inelastic deuteron scattering reported by Grotdal et al.³⁾ The reader is asked to consult these references for a more complete bibliography.

2. Source preparation and irradiation

Radioactive sources of ^{158}Er and ^{158}Ho were produced by

(heavy ion,xn) reactions on rare-earth oxide targets as listed in table 1. The rare-earth oxide powder was slurried in an acetone-water solution on 30 mg/cm² aluminum backing foil and dried. The thickness of the deposit was typically 15-20 mg/cm². Targets were covered with another foil (typically 38 mg/cm²) which served to degrade the beam to the desired energy and to contain the radioactive material during transport.

Irradiations were carried out at the Yale University heavy-ion accelerator using beam currents of 5-40 μa for periods up to 4 hours. Samples were returned to Clark University for chemical separation and counting except in those cases where ¹⁵⁸Ho was produced directly in the bombardment; they were counted at Yale.

In initial runs a chemical separation was carried out to isolate the rare-earth group of elements from contaminants.⁴⁾ In later experiments the chemical separation was skipped allowing γ-spectrum measurements to begin approximately 2 hours after the end of irradiation. Two hours was the normal driving time between Yale and Clark prior to the "energy crisis".

3. Source counting

The γ-ray spectra were obtained using a 15 cm³ Ge(Li) detector fabricated as a right circular cylinder with one open end, which gave a resolution of 2.1 keV FWHM at 1332 keV. Conventional pulse-shaping amplifiers and a 4096-channel pulse-height analyser were used in measuring the γ-ray spectrum.

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Counting rates were kept at an optimum maximum of about 10^4 counts/sec by varying the source-to-detector distance. This maximised counting statistics without impairing energy resolution. The low-energy (below 2 MeV) spectrum was recorded both with and without a 1.1 g/cm^2 cadmium absorber and the high-energy spectrum was taken with a 1.4 g/cm^2 lead absorber to suppress the low-energy contribution to the counting rate. The closest source-to-detector distance was 1 cm. The incidence of summing between time-correlated γ -rays and x-rays was estimated from spectra taken with and without absorbers.

Coincidence spectra were measured using the 15 cm^3 detector and a 33 cm^3 detector of similar design with a 2.2 keV resolution. The detectors were positioned in a coaxial geometry during these experiments and measurements were made with a fast-slow coincidence unit and a system of digital gates. Output pulses from the ADC of the gating detector were selected by setting digital windows on the spectrum regions of interest. Pulses from the other detector with the proper time relationship to the gating pulses (resolving time 40 nsec) were selectively routed and stored in the memory of the pulse-height analyser. Typically, eight gates were set and eight 512-channel coincidence spectra were recorded in each experiment. In order to identify background contributions, off-peak gates were set for each peak. The spectrum from each background gate was then subtracted from the corresponding peak gate. The true/chance coincidence ratio for the system was about 140.

4. Gamma-ray energy and intensity measurements

The energy calibration was made using sources supplied by the International Atomic Energy Agency (IAEA): ^{241}Am , ^{57}Co , ^{22}Na , ^{137}Cs , ^{88}Y and ^{60}Co . Sources of ^{133}Ba , $^{110\text{m}}\text{Ag}$ and ^{56}Co were also used. The IAEA sources were also used as primary standards for construction of detector photopeak efficiency curves. Photopeak and escape peak efficiency curves compared favorably with previous system calibrations.⁴⁾

The data reduction process for experimental γ -ray spectra was almost entirely automated. Gamma-ray energies and intensities and the associated errors were determined using the computer code, SAMPO, developed by Routti and Prussin.⁵⁾ Several other computer codes were used to facilitate intensity corrections due to the absorbers, to determine half-lives, to sort γ -rays of interest from impurity peaks, and to construct the level scheme.

5. Half-life studies

Gamma-ray spectra recorded as a function of time following bombardment were used to assign activities to the $A=158$ decay chain and to identify spurious peaks arising from summing of γ -rays uncorrelated in time. This method of assignment is reliable, as the impurities produced during the bombardments all have half-lives significantly different from ^{158}Er .

Two types of experiments were performed; the study of γ -ray spectra from ^{158}Er sources in which the ^{158}Ho daughter was in transient equilibrium, and the study of the decay of $^{158\text{g}}\text{Ho}$ and

^{158m}Ho produced directly in bombardments. The spectra obtained from the equilibrium sources were of superior quality in terms of energy resolution and statistics because of the better characteristics of the detection equipment available at Clark. For this reason the results reported here are based on the equilibrium sources. The ^{158}Ho spectra directly produced and recorded as a function of time were used to confirm assignments in the equilibrium spectra. Further confirmation of the activity assignments was gained by comparison of our results with the recent work of Harmatz and Handley⁶⁾ and Bunker⁷⁾ for ^{158}Er decay.

A determination of the half-life of ^{158}Er made by following the γ -decay of the two strong lines, 248.6 keV and 386.9 keV, over a period of four half-lives, gave 2.27 ± 0.18 h. The error estimate in the half-life measurement includes contributions from error in the intensity measurement of the photopeaks and the error over several determinations. The half-lives of the ^{158}Ho isomers were not determined with exceptional precision in our experiments.

6. Results

Typical γ -ray spectra for the low- and high-energy regions of a ^{158}Er equilibrium source are shown in fig. 1. Only peaks belonging to the A=158 decay chain are labelled with energy values rounded to the nearest integer. Some of the lines assigned to the mass chain are not discernable because of the choice in ordinate scale. Impurity peaks were identified on the basis of half-life, and in the case of very weak lines, on their intensity

relative to a stronger impurity line, where half-life data are reliable.

Gamma rays belonging to the decay of ^{158}Er were assigned on the basis of agreement with conversion electron work of Harmatz and Handley⁶⁾ and the γ -ray studies of Bunker.⁷⁾ All remaining γ -rays decaying with a 2.3-h half-life were assumed to be from decay of ^{158}Ho even though direct observation of some of the weaker transitions was not made in the experiments in which ^{158}Ho was produced directly. Transitions assigned by this indirect procedure constitute less than 5% of the total γ -ray intensity.

The γ -ray energies and intensities associated with the decay of ^{158}Ho in equilibrium with ^{158}Er are listed in table 2. Transitions are encoded where possible in a way that indicates their placement in the ^{158}Dy level scheme; for example, the 946.4 keV transition which is placed from the I=2 member of the γ -vibrational band to the ground state is designated, $2\gamma \rightarrow 0g$, and the 948.8 keV transition which de-excites the I=4 member of the K=4 band is labelled, $44 \rightarrow 2\gamma$. Otherwise, the rounded level energy is used; 213.6 keV, $1528 \rightarrow 5\gamma$.

Internal conversion coefficients and multipolarity assignments were deduced by combining our γ -ray intensity data with the conversion electron data of Abdurazakov *et al.*¹⁾ The intensity scales were normalised to the theoretical value (refs.^{8, 9)} for an E2 assignment at 218.2 keV. Experimental and theoretical conversion coefficients are presented in table 3 together with the multi-

polarity assignments. Conversion coefficients are reported only for those transitions where the correspondence in energy between the γ -ray and conversion-electron transitions is unambiguous. A multipolarity assigned as M1 is not meant to preclude any admixture of E2 character or vice versa.

The results of the coincidence experiments are presented in table 4. Weak coincidences of questionable validity are in parentheses. In order for a transition to be considered a strong coincidence, the peak in the coincidence spectrum had to be clearly distinguishable when compared with the background spectrum of the adjacent Compton gate and the relationships among lines seen in coincidence must be in agreement with the proposed decay scheme.

The decay scheme proposed for ^{158}Ho is shown in figs. 2 and 3. The scheme presented here is basically that of ref.¹⁾ with the addition of several new levels for existing bands and the establishment of another K=2 band. For visual ease the scheme has been separated into two figures. Fig. 2 contains the positive parity bands of ^{158}Dy for which a reasonable understanding in terms of the systematic behavior of deformed nuclei is realised. In fig. 3, the negative parity states are shown together with several positive parity states of uncertain character. It is suggested that the reader consult fig. 2 for comfort and fig. 3 for challenge.

The scheme as presented in figs. 2 and 3 includes 84 of the 143 γ -rays assigned to ^{158}Ho decay. One transition is assigned in two locations. Approximately 10% of the total γ -ray intensity

is unassigned. Log ft values which are shown adjacent to energy values in figs. 2 and 3 were calculated assuming that the β -decay feed came from a single level in the parent ^{158}Ho , either the ground state, 5^+ isomer, or the metastable, 2^- isomer, at 72 keV. This assumption led to no ambiguities as there is an obvious choice for the origin of β -feeding for each level in ^{158}Dy . The uncertainty in the log ft values is about 0.1 unit.

7. The ^{158}Dy level scheme

In the following paragraphs, the properties of levels in ^{158}Dy are discussed individually or in groups where appropriate.

7.1 THE GROUND STATE ROTATIONAL BAND

Previous reaction and decay studies^{2,3,10-12}) have firmly established the rotational energy levels for the ground state band in ^{158}Dy . For the first time we report evidence for the population in β -decay of the 8^+ member at 1044.1 keV. The first four members of the rotational band are confirmed by the coincidence results (table 4).

7.2 THE BETA VIBRATIONAL BAND

The rotational members of the $K=0$ β -vibrational band were populated up to spin 6 in ^{158}Ho β -decay. Again, agreement with the reaction work is quite satisfactory with band members identified as follows: $(K\Gamma^\pi)$ 00^+ at 991.1 keV, 02^+ at 1085.4 keV, 04^+ at 1280.1 keV and 06^+ at 1551.2 keV. Abdurazakov et al.¹) see only decay from the 00^+ and 02^+ members of the band and their value of the energy of the band head, 986.1 keV, is considerably lower than

we report.

7.3 THE GAMMA VIBRATIONAL BAND

The rotational members of the $K=2$ γ -vibrational band were populated up to spin 7 and are characterised as: 22^+ , 946.4 keV; 23^+ , 1044.8 keV; 24^+ , 1163.6 keV; 25^+ , 1315.0 keV; 26^+ , 1486.4 keV and 27^+ , 1676.9 keV. The placement of the 26^+ member at 1486.4 keV is in disagreement with Abdurazakov et al. but agrees with the reaction work of Jett and Lind.²⁾

7.4 A $K=2$ ROTATIONAL BAND AT 1851.8 KEV

A $K=2$ rotational band with the following members has been identified: 22^+ , 1851.9 keV; 23^+ , 1940.8 keV; 24^+ , 2055.6 keV; 25^+ , 2210.8 keV and 26^+ , 2393.3 keV. This band has been constructed on the basis of energy fit, intensity balance and the de-excitation pattern. There is no coincidence evidence in support of this band due to the low efficiency of our detectors for high energy γ -rays and thus this band assignment must be considered tentative. The quality of the energy fits and the pattern of de-excitation to the ground- and γ -band are consistent with one's expectation for a $K=2$ rotational band and we feel the evidence is moderately convincing at this stage.

7.5 A TWO-QUASIPARTICLE BAND

A rotational band built on a two-quasineutron state has been found in agreement with Abdurazakov et al. The band head, 44^+ is found at 1895.2 keV with the 45^+ member at 2022.0 keV and the 46^+ member at 2153.6 keV. The 46^+ member is a new level

reported here. Transitions to the 2^+ - 5^+ members of the γ -vibrational band are seen to de-excite the 44^+ band head by E2 transitions.

The 46^+ member de-excites to the 4^+ member of the γ -vibrational band and probably to the 5^+ member as well. The $46^+ \rightarrow 25^+$ transition at 838.7 keV contains a degree of uncertainty because of the presence of a line at the same energy in one of the radioactive contaminants, ^{159}Dy . The intensity of the 838.7 keV transition in ^{158}Ho decay was deduced by estimating the intensity of the ^{159}Dy component from other ^{159}Dy lines seen in our spectra and using the reported ^{159}Dy decay scheme.¹³⁾ The intensity of the 838.7 keV line in our spectra is more than twice what one expects for the comparable line in ^{159}Dy and therefore could be determined with a reasonable degree of certainty.

Reasons for assigning these levels as a two-quasineutron rotational band will be taken up in the discussion section.

7.6 THE NEGATIVE PARITY STATES

Levels with negative parity were found at 1397.1 keV, 1441.7 keV, 1528.0 keV and 2606.6 keV. The negative parity assignment for these levels is based on the observation of at least one transition with E1 character which de-excites the level to a positive parity state. The levels at 1397.1 keV and 1528.0 keV appear to correspond to the 3^- and 5^- levels, respectively, reported by Grottdal et al.³⁾ Levels at 1368.5 keV, 1371.7 keV, 1514.1 keV and 2659.7 keV are also tentatively given negative parity assignments for reasons considered in the discussion.

7.7 OTHER LEVELS

Four other levels were placed in the ^{158}Dy scheme based on energy combinations. They are the levels at 2107.6 keV, 2382.4 keV, 2409.6 keV and 2437.4 keV. All of these levels have positive parity and a spin of 3 or 4.

8. Discussion

In this section we compare the ^{158}Ho decay scheme with various aspects of nuclear theory.

8.1 LOW LYING COLLECTIVE LEVELS IN ^{158}Dy

Models dealing with rotational excitation are either macroscopic or microscopic models. The macroscopic models depend on phenomenological parameters which describe properties of the nucleus while microscopic models use single particle states and their interactions to derive these properties. In table 5 a comparison is made between the experimental results and four phenomenological models. The VMI model is the variable-moment-of inertia model proposed by Mariscotti et al.¹⁴⁾ In this model the effective moment of inertia $\mathcal{I}(I)$ depends on the spin, I . Das et al.¹⁵⁾ proposed the MIX-VMI model which takes into account the interaction between the ground state and vibrational bands. The Sood model¹⁶⁾ is a purely empirical relation. The model proposed by Holmberg and Lipas¹⁷⁾ describes the rotational bands by a two parameter formula deduced from experimental systematics which can also be derived from nuclear hydrodynamics. It can be seen from table 5 that all of the models reproduce the experimental results very well.

The rotational constant $\hbar^2/2I$ was calculated for the A=158, 160, 162 and 164 isotopes of dysprosium from the experimental results of this work, Gunther et al.¹⁸⁾, Wood and Brenner¹⁹⁾, and Gujrahi and D'Auria²⁰⁾ using an nth-order regression analysis. A plot of the rotational constant as a function of mass number for the ground state and the γ -vibrational bands of these isotopes is found in fig. 4. It can be seen that there is a smooth trend toward larger values of $\hbar^2/2I$ indicating a smaller moment of inertia. The general trend is for the γ -band to have a larger moment of inertia than the ground band which is what one expects. However, the moment of inertia for the ¹⁵⁸Dy γ -vibrational band appears to be smaller. This observation agrees with that of Jett and Lind.²⁾ The reason for this behaviour is not understood.

The values for the rotational constant $\hbar^2/2I$ and the coefficient B of the $I^2(I+1)^2$ term for ¹⁵⁸Dy are presented in table 6.

8.2 ANALYSIS OF INTERBAND TRANSITION INTENSITIES

The Bohr-Mottelson model assumes the nucleus to be an axially symmetric rotor and that rotational and intrinsic motions do not perturb each other. If this is the case then the ratio of E2 reduced transition probabilities for E2 transitions between vibrational states and the ground state should be simply the ratio of the squares of the appropriate Clebsch-Gordan coefficients. From the previous discussion we have seen that there is rotational-vibrational interaction and a correction term becomes necessary.

To the first order in spin dependence the E2 reduced transition value, B(E2) value, becomes²²⁾

$$B(E2; K=2, I_{\gamma} \rightarrow K=0, I_g) = \langle I_{\gamma} 22-2 | I_g 0 \rangle^2 |M_{1\gamma}|^2 \{1+z_2 F(I_{\gamma}, I_g)\}^2 \quad (1)$$

Here $M_{1\gamma}$ is the leading-order matrix element that connects the γ -band with the ground state band and z_2 is the band-mixing parameter.

A convenient way of extracting a z_2 value from experimental data is by means of Mikhailov plot.²³⁾ The quantity

$$F(I_{\gamma}, I_g) = \frac{\{B(E2; K=2, I \rightarrow K=0, I_g)\}^{1/2}_{\text{relative}}}{\langle I_{\gamma} 22-2 | I_g 0 \rangle} \quad (2)$$

is calculated for each transition depopulating a band level. A plot of $F(I_{\gamma}, I_g)$ against $I_g(I_g+1) - I_{\gamma}(I_{\gamma}+1)$ should lead to a straight line with z_2 as the slope if eq.(2) adequately describes the data. Fig. 5 is such a plot for the ¹⁵⁸Dy data. The relative B(E2) value in eq.(2) is calculated from $(\gamma\text{-ray intensity})/E_{\gamma}^5$. Only the $\Delta I = \pm 2$ transitions are used in determining z_2 to avoid the complication of possible M1 admixtures to the transitions. The relative $F(I_{\gamma}, I_g)$ values were normalised so that $F(2,0)=1.00$. The best fit through the four points leads to a value $z_2 = 0.093 \pm 0.012$. The uncertainty is due to the uncertainty in γ -ray intensities. The fifth point $F(6,8)$ is very low with respect to the curve fit through the other points and is assumed to be erroneous. The two $\Delta I = 0$ points are included and, within error, appear in agreement with the other points. Graetzer et al.¹²⁾ calculates a value

$z_2 = 0.04 \pm 0.03$ from their data and the results of Gromov.²⁴⁾

There is a disagreement as to the z_2 value for ^{160}Dy . Gunther et al.¹⁸⁾ report a consistent z_2 value with an average of 0.0419 ± 0.035 . Keller and Zganjar²⁵⁾ corroborate the conclusion of the independent investigations by Jaklevic et al.²⁶⁾ and Ludington et al.³⁷⁾ that there is no consistent value for z_2 in ^{160}Dy . Gujrathi and D'Auria²⁰⁾ calculate a value of 0.05 for ^{164}Dy . Although the information is sketchy, taken together, it appears that a trend toward increasing band-mixing is taking place with decreasing A among the dysprosium isotopes.

Of the dysprosium isotopes reported in the literature only ^{158}Dy and ^{156}Dy have a β -vibrational band populated either by beta-decay or in reaction work. The possibility of band-mixing was investigated for this band in a manner similar to the one used for the γ -band. A Mikhailov plot for the β -band is shown in fig. 6. The best fit to the points gives a value of $z_0 = 0.058 \pm 0.019$. Graetzer et al.¹²⁾ calculate a value of 0.025 ± 0.015 . From their conversion electron work they have determined that the $\Delta I = 0$ transitions are of predominantly E0 character which could account for the large deviation from the trend of the other points. The F(2,4) value is inconsistent and was ignored in the fitting procedure.

8.3 THE TWO-QUASINEUTRON BAND

The ground state of ^{158}Ho , an odd-odd nucleus has $KI^\pi = 55^+$ resulting from the coupling of an odd-proton and odd-neutron ($\pi 7/2^- [523] + \nu 3/2^- [521]$) according to Harmatz and Handley.⁶⁾

In the β -decay of ^{158}Ho the odd proton changes to a neutron. If the resulting neutron is in an excited intrinsic state and couples with another neutron a two-quasineutron level is formed.

Pyatov and Soloviev²⁸⁾ have calculated the energies for the low-lying two-quasiparticle states for ^{158}Dy from the average-field single particle levels for neutron and proton systems in the $150 < A < 160$ region. One of the possible two-neutron configurations for ^{158}Dy that they predict is a 4^+ level ($\nu\ 5/2^-[523] + \nu\ 3/2^-[521]$) at approximately 1.7 MeV which should be fed by an allowed-unhindered beta-decay with $\log ft$ in the range 4.5-5.0.

In the present decay scheme the level at 1895.2 keV de-excites to the 2^+ , 3^+ and 4^+ members of the $K = 2$ γ -vibrational band by E2 transitions and also the 5^+ member by a transition of unknown multipolarity. These results together with those of ref.¹⁾ establish the spin and parity of the 1895.2 keV level as 4^+ . The de-excitation of this level proceeds exclusively to the γ -vibrational band indicating that the K-value of the parent level is high, although attempts to deduce K from reduced transition probabilities are inconclusive. The experimental $\log ft$ of 4.9 which is consistent with an a.u. β -transition is in good agreement with that obtained by Abdurazakov *et al.*⁵⁾ and we concur with their assignment of the 1895.2 keV level as the ($\nu\ 5/2^-[523] + \nu\ 3/2^-[521]$), two-quasineutron state, predicted by Pyatov and Soloviev²⁸⁾. The levels at 2022.0 keV and 2153.6 keV are proposed as the 5^+ and 6^+ rotational members of the two-neutron state. The decay pattern and $\log ft$ values are not inconsistent with this assignment.

Abdurazakov et al. have assigned the 1578.1 keV γ -ray de-exciting the 1895.0 keV level to the 4^+ member of the ground state rotational band. While the energy fit is good, the lack of any other transitions from the $K = 4$ band to the $K = 0$ band makes this assignment questionable. This transition is not placed in the present scheme.

8.4 A $K=2$ ROTATIONAL BAND AT 1851.9 KEV

A rotational band with $K^\pi = 2^+$ appears to be built on a band head at 1851.9 keV. The rotational sequence is reproduced by the Bohr-Mottleson formula with a rotational constant $\hbar^2/2I$ of 14.5 keV, an increase over the ground state moment of inertia. The assignment as a $K = 2$ band is based on the fact that the rotational sequence is 2, 3, 4, 5 and 6 which excludes $K = 0$. If this band were a two-phonon ($\gamma+\beta$) vibrational band, transitions to the β -band would be expected and indeed two are placed in the scheme. The reduced transition probabilities do not indicate that the transition to the γ -vibrational band are preferred over transitions to the ground state band which one expects for a two-phonon vibrational band. The present evidence suggests that this may possibly be a two-phonon ($\gamma+\beta$) vibrational band.

8.5 NEGATIVE PARITY STATES

Several new negative parity states have been identified in ^{158}Dy near 1400 keV of excitation energy (fig. 3). The identification and assignment of these states is somewhat ambiguous because the data do not permit us to assign unique spins and parities in all

cases. In addition, the apparent presence of three of the four possible octupole band heads within an energy spread of 100 keV insures that these states will be highly K-admixed and that the rotational bands will be distorted in their energy progression. Nevertheless, with the aid of the (d,d') results of Grottdal et al.³⁾ and in analogy to the level scheme of ¹⁶⁰Dy, where a meticulous study has been made by Gunther et al.¹⁸⁾, it has been possible to propose assignments with a reasonable degree of confidence for the K = 0, 1 and 2 octupole band heads in ¹⁵⁸Dy. Here our K-assignments are meant to convey our feelings about the predominant K component of the state and are not to be construed as excluding large components of other K-values. Details of evidence for these assignments will be summarised below.

The $KI^\pi = 11^-$ state at 1368.5 keV. A level at 1368.5 keV has been determined by the observation of two γ -rays, 1368.5 keV and 1269.7 keV, which de-excite to the lowest two members of the ground state rotational band of ¹⁵⁸Dy. The multipolarities of these transitions are not known and the level is placed on energy fit alone. An assignment of 11^- for this level is based on the following plausible arguments. In an attempt to assign a spin and parity to the 1368.5 keV state let us first assume it to have positive parity which restricts possible spins to the range, 0-2. This assumption is invalidated when the systematic level structure of even-even nuclei is considered. The only states in even-even nuclei of these I^π assignments at this excitation energy are members of one-phonon β - or γ - vibrational bands or possibly two-quasiparticle states. In ¹⁵⁸Dy all the low-spin members of the

β^- and γ -vibrational bands are unambiguously assigned at other energies by reaction and decay studies, and there are no appropriate two-quasiparticle states predicted²⁸). Assuming negative parity, however, leads to a consistent understanding of the level character. Negative parity requires the state to have $I=1$ because the 1368.5 keV and 1269.7 keV de-exciting transitions will necessarily be $E1$. With the assumption of $E1$ multipolarity for these transitions one can go on to estimate a K assignment for the levels by comparison of experimental and theoretical $B(E1)$ values (see table 7). The experimental value is consistent with an assignment of $K=1$ for this level.

The $K=2$ one-phonon octupole vibrational band. A $K=2$ one-phonon octupole vibrational band is proposed with energies, 1371.7, 1397.1, 1514.1 and 1528.0 keV for spins, 2^- , 3^- , 4^- and 5^- , respectively. Grotdal et al.³) identified levels at 1398, 1513 and 1527 keV in their (d,d') spectra and assigned the 1398 keV level as 3^- and the 1527 keV level as (5^-) on the basis of the angular dependence of the (d,d') cross section. The level at 1513 keV was not given an assignment and a level was not reported at 1372 keV. A careful search of the reaction data failed to reveal any evidence for a 1^- state in the appropriate energy region which led Grotdal et al. to conclude that the 1398 and 1527 keV levels belonged to a band with $K>1$.

Our γ -ray data confirm these assignments with the observation of $E1$ transitions to the ground state rotational band from levels at 1397.1 and 1528.0 keV. The levels at 1371.7 and 1514.1 keV are

somewhat more tenuous. The assignment of the 1371.7 keV level as spin 2^- seems likely with the observation of a probable E1 transition to the 2^+ member of the ground band and transitions to the 2^+ and 3^+ members of the γ -vibrational band. An estimate of the K assignment can be made from the B(E1) ratios for depopulation to the γ -vibrational band (see table 7). Here we can only set a lower limit on the B(E1) ratio because the 326.9 keV line appears as a composite in the spectrum with a 326.3 keV impurity line belonging to ^{157}Tb . The limiting ratio tends to support a K=2 assignment for this level.

The level at 1514.1 keV is denoted $KI^\pi = 24^-$ on the basis of a single transition of unknown multipolarity which de-excites to the 4^+ member of the ground band and the observation of a level at this energy by Grotdal et al.

While the evidence for the assignment of the K=2 octupole vibrational band is not overwhelming, the assignments are supported by a comparison with the level scheme of Gunther et al.¹⁸⁾ (fig. 7) where a very similar pattern exists for the spacing of the rotational band members in ^{160}Dy . Their scheme which is based on very convincing experimental evidence provides support for the close placement of the K=1 and K=2 phonon band heads. In ^{160}Dy these states are found within about 20 keV of each other with the K=2 band head lying lowest in energy. It is also supportive of our scheme to note that the pattern of anomalous behavior of the B(E1) ratios for de-excitation of the 23^- state to the ground band is analogous to that in ^{160}Dy .

The $KI^\pi = 01^-$ state at 1441.7 keV. A level at 1441.7 keV with $I^\pi = 1^-$ is assigned on the basis of its de-excitation to the ground state and to the 02^+ rotational level by an E1 transition. Grottdal et al. found evidence for the existence of a level at 1440 keV in their (d,d') spectra and it is assumed that we are observing the same level. While the B(E1) ratio for de-excitation to the ground band falls between the values for K=0 and K=1, an assignment of K=0 is favored because the K=0 band head is predicted to lie somewhat higher in excitation energy than the band heads for K=1 and K=2²⁹) (fig. 7).

A $I^\pi = 1^-$ level at 2606.6 keV is clearly established by the observation of E1 transitions to the ground and first excited states of ¹⁵⁸Dy. Another level at 2659.7 keV is tentatively given as assignment of (1^-) based solely on the de-excitation pattern and agreement between experimental and theoretical B(E1) values. No such agreement was possible if positive parity for the level is chosen. We have no theoretical understanding of either at these levels.

8.6 OTHER LEVELS

Levels at 2107.6 keV, 2382.4 keV, 2409.6 keV and 2437.4 keV are proposed with spin and parity of 3^+ or 4^+ . These assignments are supported by the multipolarities and decay patterns of the de-exciting transitions. No attempt at interpretation is made for these levels.

9. Concluding remarks

The study of the γ -rays following β -decay of ^{158}Ho has led to a rather complete level scheme for ^{158}Dy . Unassigned γ -ray intensities amount to less than 10% of the total intensity observed. While a considerable amount of the structure of ^{158}Dy levels is qualitatively understood, a great deal of quantitative work remains to be done. In particular, the assignment and interpretation of the negative parity states requires further effort. With the advent of the more detailed data about these levels one could hope to understand more quantitatively the relative $B(E1)$ values for de-excitation of these levels. It is curious that there is some evidence for assigning relatively pure K values to some of these states, while other results indicate that considerable mixing is occurring.

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Table 1
Target materials and reaction parameters

Target ^{a)}	Enrichment (%)	Reaction	Bombardment Energy (MeV)
$^{148}\text{Nd}_2\text{O}_3$	95.4	$(^{14}\text{N}, 4n)^{158}\text{Ho}$	60
$^{150}\text{Sm}_2\text{O}_3$	95.5	$(^{12}\text{C}, 4n)^{158}\text{Er}$	64
$^{151}\text{Eu}_2\text{O}_3$	93.4	$(^{11}\text{B}, 4n)^{158}\text{Er}$	56

^{a)} Target materials were obtained from the Isotopes Development Center, Oak Ridge National Laboratory.

Table 2
Gamma rays assigned to ^{158}Ho decay

E_{γ} (keV)	$I_{\gamma}^a)$	Assignment ^{b)}
98.9 $\pm$ 0.1	703 $\pm$ 84	2g $\rightarrow$ 0g
105.6 $\pm$ 0.1	1.5 $\pm$ 0.4	
213.6 $\pm$ 0.2	15.3 $\pm$ 3.6	1528 $\rightarrow$ 5 γ
218.2 $\pm$ 0.1	1000 $\pm$ 90	4g $\rightarrow$ 2g
275.2 $\pm$ 0.2	0.6 $\pm$ 0.2	
294.1 $\pm$ 0.1	2.7 $\pm$ 0.3	
320.5 $\pm$ 0.1	118 $\pm$ 9	6g $\rightarrow$ 4g
(326.9 $\pm$ 0.4)	($\sim$ 10) $\pm$	1372 $\rightarrow$ 3 γ
351.4 $\pm$ 0.1	1.7 $\pm$ 0.2	
354.2 $\pm$ 0.1	2.3 $\pm$ 0.3	
406.0 $\pm$ 0.1	2.6 $\pm$ 0.4	8g $\rightarrow$ 6g
418.1 $\pm$ 0.1	8.9 $\pm$ 0.8	
425.4 $\pm$ 0.1	22.4 $\pm$ 1.8	1372 $\rightarrow$ 2 γ
442.2 $\pm$ 0.2	1.2 $\pm$ 0.3	6 γ $\rightarrow$ 8g
447.2 $\pm$ 0.2	1.4 $\pm$ 0.3	
462.1 $\pm$ 0.1	9.9 $\pm$ 0.9	
580.3 $\pm$ 0.1	8.0 $\pm$ 0.8	44 $\rightarrow$ 5 γ
630.2 $\pm$ 0.1	14.4 $\pm$ 1.3	
642.7 $\pm$ 0.2	4.1 $\pm$ 0.6	4 β $\rightarrow$ 6g
660.7 $\pm$ 0.1	4.5 $\pm$ 0.5	32 $\rightarrow$ 2 β
668.7 $\pm$ 0.1	4.2 $\pm$ 0.6	
676.9 $\pm$ 0.1	15.4 $\pm$ 1.3	5 γ $\rightarrow$ 6g
706.9 $\pm$ 0.1	12.1 $\pm$ 1.2	54 $\rightarrow$ 5 γ
715.4 $\pm$ 0.1	2.4 $\pm$ 0.9	62 $\rightarrow$ 7 γ
726.4 $\pm$ 0.2	10.0 $\pm$ 2.1	
727.7 $\pm$ 0.1	77.1 $\pm$ 6.7	3 γ $\rightarrow$ 4g
731.4 $\pm$ 0.1	65.2 $\pm$ 5.5	44 $\rightarrow$ 4 γ
740.6 $\pm$ 0.1	9.4 $\pm$ 1.0	42 $\rightarrow$ 5 γ
766.3 $\pm$ 0.1	6.1 $\pm$ 0.7	22 $\rightarrow$ 2 β
768.4 $\pm$ 0.1	23.1 $\pm$ 2.0	2 β $\rightarrow$ 4g
776.9 $\pm$ 0.1	10.1 $\pm$ 1.2	32 $\rightarrow$ 4 γ
792.3 $\pm$ 0.1	1.9 $\pm$ 0.5	2108 $\rightarrow$ 5 γ
807.1 $\pm$ 0.1	6.1 $\pm$ 1.8	22 $\rightarrow$ 3 γ
838.7 $\pm$ 0.1	15.6 $\pm$ 6.2	64 $\rightarrow$ 5 γ
846.7 $\pm$ 0.2	256 $\pm$ 44	4 γ $\rightarrow$ 4g
847.4 $\pm$ 0.2	262 $\pm$ 44	2 γ $\rightarrow$ 2g
850.4 $\pm$ 0.1	238 $\pm$ 20	44 $\rightarrow$ 3 γ
858.2 $\pm$ 0.1	17.5 $\pm$ 2.1	54 $\rightarrow$ 4 γ
891.0 $\pm$ 0.2	21.8 $\pm$ 4.7	
892.2 $\pm$ 0.2	19.8 $\pm$ 4.6	0 β $\rightarrow$ 2g
896.1 $\pm$ 0.1	31.0 $\pm$ 2.7	32 $\rightarrow$ 3 γ , 52 $\rightarrow$ 5 γ
908.7 $\pm$ 0.2	3.2 $\pm$ 0.9	
933.9 $\pm$ 0.1	4.1 $\pm$ 0.5	
945.7 $\pm$ 0.1	417 $\pm$ 52	3 γ $\rightarrow$ 2g

946.4 ± 0.2	189 ± 40	2γ → 0g
948.8 ± 0.1	372 ± 31	44 → 2γ
962.8 ± 0.1	7.4 ± 0.8	4β → 4g
977.4 ± 0.1	26.0 ± 2.3	54 → 3γ
986.3 ± 0.1	14.7 ± 1.5	2β → 2g
990.0 ± 0.1	12.8 ± 1.2	64 → 4γ
994.5 ± 0.1	94.3 ± 7.8	32 → 2γ
997.6 ± 0.1	66.3 ± 5.6	5γ → 4g
1010.7 ± 0.1	13.0 ± 1.4	42 → 3γ
1012.4 ± 0.2	6.4 ± 1.1	
1024.7 ± 0.2	2.9 ± 0.5	
1038.9 ± 0.5	2.5 ± 1.5	7γ → 6g
1047.4 ± 0.1	17.4 ± 1.5	52 → 4γ
1063.1 ± 0.1	26.5 ± 2.7	2108 → 3γ
1064.8 ± 0.1	56.3 ± 5.0	4γ → 2g
1080.0 ± 0.1	12.8 ± 1.4	1397 → 4g
1085.5 ± 0.1	8.2 ± 1.0	2β → 0g
1095.1 ± 0.2	2.6 ± 0.6	2410 → 5γ
1109.2 ± 0.1	7.5 ± 0.8	42 → 2γ
1118.4 ± 0.2	1.9 ± 0.5	
1143.1 ± 0.1	5.6 ± 0.7	
1169.2 ± 0.1	8.0 ± 0.8	6γ → 4g
1181.2 ± 0.2	12.4 ± 3.5	4β → 2g
1196.3 ± 0.1	9.4 ± 1.1	1514 → 4g
1201.4 ± 0.1	14.1 ± 1.5	
1210.8 ± 0.1	27.1 ± 2.3	1528 → 4g
1222.9 ± 0.2	3.4 ± 0.7	
1230.1 ± 0.1	10.8 ± 1.1	62 → 4γ
1234.0 ± 0.1	4.7 ± 0.8	6β → 4g
1245.9 ± 0.2	3.5 ± 0.6	2410 → 4γ
1262.1 ± 0.2	3.9 ± 0.6	
1269.7 ± 0.1	4.0 ± 0.7	1368 → 2g
1272.7 ± 0.1	28.3 ± 2.5	1372 → 2g
1298.2 ± 0.1	31.2 ± 2.7	1397 → 2g
1314.9 ± 0.3	3.1 ± 1.0	
1337.7 ± 0.1	9.9 ± 1.0	2382 → 3γ
1342.8 ± 0.1	11.7 ± 1.2	1442 → 2g
1364.7 ± 0.1	12.5 ± 1.2	2410 → 3γ
1368.5 ± 0.1	11.2 ± 1.2	1368 → 0g
1392.5 ± 0.1	5.0 ± 0.9	2437 → 3γ
1402.2 ± 0.1	6.8 ± 0.8	
1414.7 ± 0.1	19.5 ± 1.9	
1417.8 ± 0.1	9.6 ± 1.1	42 → 6γ
1436.0 ± 0.2	6.5 ± 0.8	2382 → 2γ
1441.7 ± 0.1	10.9 ± 1.1	1442 → 0g
1463.3 ± 0.1	39.0 ± 3.4	2410 → 2γ
1509.0 ± 0.1	12.0 ± 1.5	
1521.3 ± 0.1	20.3 ± 1.9	
1572.3 ± 0.1	7.2 ± 0.9	52 → 6g
1578.1 ± 0.1	81.3 ± 7.0	
1604.0 ± 0.2	7.4 ± 1.1	
1623.7 ± 0.1	68.8 ± 5.8	32 → 4g
1637.2 ± 0.3	2.6 ± 0.9	
1677.9 ± 0.1	10.6 ± 1.1	

1698.1 ± 0.2	8.6 ± 1.2	
1715.6 ± 0.2	2.3 ± 0.6	
1719.2 ± 0.3	1.8 ± 0.5	
1753.7 ± 0.2	7.5 ± 0.9	62 → 6g
1784.1 ± 0.1	17.1 ± 1.7	
1790.5 ± 0.2	230 ± 19	2108 → 4g
1841.8 ± 0.2	5.1 ± 1.1	32 → 2g
1851.9 ± 0.2	5.1 ± 0.7	22 → 0g
1856.4 ± 0.2	8.8 ± 0.9	
1877.0 ± 0.2	16.9 ± 1.5	
1881.1 ± 0.2	6.2 ± 0.8	
1886.3 ± 0.2	5.7 ± 0.7	
1893.9 ± 0.2	4.2 ± 0.8	52 → 4g
1913.2 ± 0.3	4.3 ± 0.7	
1918.6 ± 0.3	6.1 ± 0.7	
1949.4 ± 0.3	3.0 ± 0.4	
1956.8 ± 0.2	10.9 ± 1.0	42 → 2g
1969.8 ± 0.2	4.5 ± 0.5	
1975.8 ± 0.3	2.5 ± 0.4	
2009.5 ± 0.2	19.3 ± 1.8	2108 → 2g
2030.0 ± 0.2	8.9 ± 0.8	
2053.8 ± 0.5	2.2 ± 0.7	
2065.9 ± 0.2	32.4 ± 2.5	2382 → 4g
2075.9 ± 0.3	6.3 ± 0.8	62 → 4g
2092.9 ± 0.3	11.1 ± 1.6	2410 → 4g
2120.2 ± 0.3	23.5 ± 1.8	2437 → 4g
2147.6 ± 0.2	3.0 ± 0.5	
2188.7 ± 0.3	3.4 ± 0.6	
2202.5 ± 0.2	48.2 ± 3.4	
2222.2 ± 0.2	46.4 ± 3.3	
2311.5 ± 0.2	9.9 ± 0.9	2410 → 2g
2338.9 ± 0.2	3.7 ± 0.4	2437 → 2g
2355.9 ± 0.3	2.1 ± 0.4	
2372.9 ± 0.2	4.9 ± 0.5	
2393.8 ± 0.3	3.9 ± 0.5	
2411.2 ± 0.2	3.0 ± 0.4	
2445.4 ± 0.2	3.7 ± 0.5	
2465.6 ± 0.2	2.8 ± 0.4	
2507.8 ± 0.2	13.1 ± 1.0	2607 → 2g
2526.0 ± 0.2	3.1 ± 0.4	
2546.6 ± 0.2	39.1 ± 2.7	
2560.9 ± 0.2	2.9 ± 0.4	2660 → 2g
2606.5 ± 0.2	76.8 ± 5.4	2607 → 0g
2659.7 ± 0.2	5.4 ± 0.4	2660 → 0g
2755.1 ± 0.2	5.6 ± 0.6	
2874.9 ± 0.2	2.7 ± 0.3	

a) Normalised to 1000 at 218 keV.

b) Symbols designating the transition assignments are explained in the text.

Table 3

K-conversion coefficients and multipolarities of transitions

in ^{158}Dy

E_{γ} (kev)	$\alpha_K^a)$	Theoretical Conversion Coefficients $d)$			Multipolarity
		E1	E2	M1	
98.9	$1.2 \pm 0.2 (0)^b)$	2.6(-1)	1.2(0)	2.0(0)	E2
218.2	$1.3 \pm 0.2 (-1)^c)$	3.5(-2)	1.3(-1)	2.3(-1)	E2
320.5	$5.0 \pm 0.9 (-1)$	1.2(-2)	4.2(-2)	8.1(-2)	E2
676.9	$6.1 \pm 1.7 (-3)$	2.3(-3)	5.9(-3)	1.2(-2)	E2
706.9	$6.2 \pm 1.7 (-3)$	2.1(-3)	5.4(-3)	1.1(-2)	E2
731.4	$4.8 \pm 1.3 (-3)$	2.0(-3)	5.0(-3)	1.0(-2)	E2
776.9	$7.2 \pm 1.9 (-3)$	1.7(-3)	4.4(-3)	8.5(-3)	M1
807.1	$3.0 \pm 1.2 (-3)$	1.6(-3)	4.1(-3)	7.7(-3)	E2
847.4	$4.4 \pm 0.5 (-3)$	1.5(-3)	3.6(-3)	6.8(-3)	E2/M1
850.4	$3.8 \pm 0.7 (-3)$	1.5(-3)	3.6(-3)	6.8(-3)	E2
858.2	$3.2 \pm 1.1 (-3)$	1.4(-3)	3.5(-3)	6.6(-3)	E2
892.2	$4.7 \pm 1.9 (-3)$	1.3(-3)	3.3(-3)	6.1(-3)	Not E1
945.7	$1.7 \pm 0.3 (-3)$	1.2(-3)	2.9(-3)	5.2(-3)	Not M1
946.4	$3.5 \pm 0.6 (-3)$	1.2(-3)	2.9(-3)	5.2(-3)	E2
948.8	$2.5 \pm 0.4 (-3)$	1.2(-3)	2.9(-3)	5.2(-3)	E2
977.4	$2.3 \pm 0.6 (-3)$	1.1(-3)	2.7(-3)	4.8(-3)	E2
997.6	$3.3 \pm 0.9 (-3)$	1.1(-3)	2.6(-3)	4.6(-3)	E2
1010.7	$1.6 \pm 0.4 (-3)$	1.0(-3)	2.5(-3)	4.5(-3)	Not M1
1063.1	$1.5 \pm 0.4 (-3)$	9.4(-4)	2.3(-3)	3.9(-3)	Not M1
1064.8	$2.9 \pm 0.6 (-3)$	9.4(-4)	2.3(-3)	3.9(-3)	E2

1085.5	$1.6 \pm 0.6 (-3)$	$9.0 (-4)$	$2.2 (-3)$	$3.7 (-3)$	E2
1169.2	$2.6 \pm 0.7 (-3)$	$7.8 (-4)$	$1.9 (-3)$	$3.1 (-3)$	Not E1
1210.8	$7.1 \pm 1.9 (-4)$	$7.2 (-4)$	$1.8 (-3)$	$2.9 (-3)$	E1
1230.1	$1.8 \pm 0.5 (-3)$	$7.0 (-4)$	$1.7 (-3)$	$2.8 (-3)$	E2
1234.0	$1.8 \pm 0.5 (-3)$	$7.0 (-4)$	$1.7 (-3)$	$2.8 (-3)$	E2
1272.7	$1.2 \pm 0.3 (-3)$	$6.6 (-4)$	$1.6 (-3)$	$2.6 (-3)$	Not M1
1298.2	$6.5 \pm 1.8 (-4)$	$6.3 (-4)$	$1.5 (-3)$	$2.5 (-3)$	E1
1337.7	$1.1 \pm 0.3 (-3)$	$6.2 (-4)$	$1.4 (-3)$	$2.3 (-3)$	E2
1342.8	$6.2 \pm 1.7 (-4)$	$6.0 (-4)$	$1.4 (-3)$	$2.3 (-3)$	E1
1417.8	$2.8 \pm 0.9 (-3)$	$5.6 (-4)$	$1.3 (-3)$	$2.0 (-3)$	M1
1436.0	$3.1 \pm 1.4 (-3)$	$5.5 (-4)$	$1.3 (-3)$	$1.9 (-3)$	M1
1463.3	$1.5 \pm 0.4 (-3)$	$5.3 (-4)$	$1.2 (-3)$	$1.9 (-3)$	Not E1
1578.1	$1.3 \pm 0.4 (-3)$	$4.8 (-4)$	$1.1 (-3)$	$1.6 (-3)$	Not E1
1623.7	$1.3 \pm 0.3 (-3)$	$4.7 (-4)$	$1.0 (-3)$	$1.5 (-3)$	Not E1
1753.7	$1.1 \pm 0.5 (-3)$	$4.1 (-4)$	$8.8 (-4)$	$1.3 (-3)$	Not E1
1790.5	$1.2 \pm 0.2 (-3)$	$4.0 (-4)$	$8.5 (-4)$	$1.2 (-3)$	M1
1956.8	$1.0 \pm 0.3 (-3)$	$3.4 (-4)$	$7.2 (-4)$	$9.6 (-4)$	Not E1
2009.5	$9.2 \pm 2.5 (-4)$	$3.3 (-4)$	$6.6 (-4)$	$8.9 (-4)$	M1
2065.9	$7.8 \pm 2.1 (-4)$	$3.1 (-4)$	$6.5 (-4)$	$8.4 (-4)$	Not E1
2075.9	$1.4 \pm 0.4 (-3)$	$3.1 (-4)$	$6.4 (-4)$	$8.3 (-4)$	Not E1
2120.2	$8.2 \pm 2.0 (-4)$	$3.0 (-4)$	$6.2 (-4)$	$7.9 (-4)$	M1
2311.5	$3.8 \pm 1.1 (-4)$	$2.6 (-4)$	$5.3 (-4)$	$6.6 (-4)$	Not M1
2338.9	$3.6 \pm 1.0 (-4)$	$2.6 (-4)$	$5.2 (-4)$	$6.4 (-4)$	Not M1
2507.8	$3.1 \pm 0.9 (-4)$	$2.3 (-4)$	$4.6 (-4)$	$5.4 (-4)$	E1
2606.5	$2.1 \pm 0.6 (-4)$	$2.1 (-4)$	$4.2 (-4)$	$4.9 (-4)$	E1

a) Computed from the γ -ray intensities of this work and the conversion electron data of ref.¹); see text for further details.

- b) The entry $1.2 \pm 0.2(0)$ is to be read $(1.2 \pm 0.2) \times 10^0$.
- c) Normalised to the K-conversion coefficient for an E2 transition.
- d) Conversion coefficients for energies up to 1500 keV from ref. 8) and above 1500 keV from ref. 9).

Table 4

Gamma rays in coincidence from the decay of ^{158}Ho

E_{γ} (keV)	Gamma rays in coincidence with E_{γ}^a
98.9	218.2, 320.5, 847.4
218.2	320.5, 727.7, (846.7), (997.6)
896.1	(946.4)
946.4	948.8
948.8	(218.2), (946.4)

^{a)} Weak coincidences are in parentheses.

Table 5

Comparisons of the energies of collective levels in ^{158}Dy
with the prediction of models described in the text

Level $I^\pi K$	Experimental Energy (keV) ^{a)}	VMI ref. ¹⁴⁾	MIX-VMI ref. ¹⁵⁾	Sood ref. ¹⁶⁾	HL ref. ¹⁷⁾
2^+_0	98.9 $\pm$ .1	98.9	99*	97.9	97.2
4^+_0	317.2 $\pm$ .1	317.0	317*	316.7	315.6
6^+_0	638.1 $\pm$ .1	635.3	635	638.6	638.3
8^+_0	1044.1 $\pm$ .1	1036.9	1034	1044.4	1045.5
2^+_2	946.4 $\pm$ .2			946.7	946.9
3^+_2	1044.8 $\pm$ .1			1042.6	1042.5
4^+_2	1163.6 $\pm$ .1			1166.2	1166.0
5^+_2	1315.0 $\pm$ .1			1314.6	1314.6
6^+_2	1486.4 $\pm$ .2			1485.3	1485.5
7^+_2	1676.9 $\pm$ .5			1676.0	1675.9
0^+_0	991.1 $\pm$ .2		991*	991.0	991.4
2^+_0	1085.4 $\pm$ .1		1083*	1084.5	1083.8
4^+_0	1280.1 $\pm$ .2		1288	1280.3	1280.7
6^+_0	1551.2 $\pm$ .1		1589	1552.0	1551.9

^{a)} Asterisks identify level energies used to obtain model parameters.

Table 6
Coefficients of the Bohr-Mottelson Formulation for
rotational levels in even-even nuclei^{a)}

Band	A (keV)	B (keV)
ground	16.18	23.8
γ	16.29	27.5
β	15.49	52.2

^{a)} ref. 21).

Table 7

Ratio of $B(E1)$ values for the transitions depopulating the
negative-parity states in ^{158}Dy

Parent Level (keV)	$\frac{E(I_i^{\pi} \rightarrow I_f^{\pi})}{E(I_i^{\pi} \rightarrow I_f^{\pi})}$	K_f^{π}	$\frac{B(E1, K_i I_i \rightarrow K_f I_f)}{B(E1, K_i I_i \rightarrow K_f I_f)}$			
				Experiment	Theory K_i	
					0	1 2
1368.5	$\frac{1368(1^- \rightarrow 0^+)}{1270(1^- \rightarrow 2^+)}$	0^+	2.3 ± 0.4		0.5	2.0 -
1371.7	$\frac{425(2^- \rightarrow 2^+)}{327(2^- \rightarrow 3^+)}$	2^+	>1.0		-	0.1 0.7
1397.1	$\frac{1298(3^- \rightarrow 2^+)}{1080(3^- \rightarrow 4^+)}$	0^+	1.4 ± 0.2		0.8	1.3 -
1441.7	$\frac{1441(1^- \rightarrow 0^+)}{1342(1^- \rightarrow 2^+)}$	0^+	0.7 ± 0.1		0.5	2.0 -
1528.1	$\frac{1210(5^- \rightarrow 4^+)}{891(5^- \rightarrow 6^+)}$	0^+	0.5 ± 0.1		0.8	1.2 -
2606.6	$\frac{2606(1^- \rightarrow 0^+)}{2507(1^- \rightarrow 2^+)}$	0^+	5.2 ± 0.5		0.5	2.0 -
2659.7	$\frac{2659(1^- \rightarrow 0^+)}{2560(1^- \rightarrow 2^+)}$	0^+	1.7 ± 0.3		0.5	2.0 -

Figure Captions

- Fig. 1 Gamma-ray spectra from the decay of ^{158}Ho in transient equilibrium with 2.3-h ^{158}Er . The data in fig. 1 were obtained with a 15cm^3 Ge(Li) detector. The higher-energy spectrum was obtained with a 1.4 g/cm^2 lead absorber. The data in figs. 1a, b and c, d are from separate experiments.
- Fig. 2 Positive parity bands as seen in the decay of ^{158}Ho in transient equilibrium with 2.3-h ^{158}Er . Energies are in keV and relative γ -ray intensities are shown in parentheses. Transitions whose assignments are confirmed by coincidence data are marked with a filled circle. Log ft values are shown adjacent to level energies.
- Fig. 3 Negative parity levels and miscellaneous positive parity levels as seen in the decay of ^{158}Ho in transient equilibrium with 2.3-h ^{158}Er . Energies are in keV, relative γ -ray intensities are in parentheses and log ft values are shown adjacent to level energies.
- Fig. 4 The rotational constant as a function of mass number for dysprosium isotopes.
- Fig. 5 Mikhailov plot for γ -transitions depopulating the γ -vibrational band in ^{158}Dy .

Fig. 6 Mikhailov plot for γ -transitions depopulating the β -vibrational band in ^{158}Dy .

Fig. 7 Negative parity bands in ^{158}Dy and ^{160}Dy . The ^{160}Dy results are those of ref.³⁾ where the dashed lines indicated calculated level energies. The ^{158}Dy experimental results are from this work and the calculations are from ref. ²⁹⁾.

Fig 1a

Fig 1b

Fig. 1c

Fig. 1d

$Q_{EC} = 4220 \text{ KEV}$

Fig. 2

EC, β^+

2⁻ 28 min
5⁺ 11 min
158 Ho

$Q_{EC} = 4220 \text{ KEV}$

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7