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Abstract

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DECAY OF Ho^{156}

The conversion spectrum of the radioactive isotope of holmium with a half-life of 56 min was studied on a double-focusing β-spectrometer at an angle $\pi\sqrt{2}$.

Ho^{156} was first discovered by Michelet et al. ([1]). The identification of this isotope was carried out by them on the basis of a study of the activity obtained upon irradiation, with 22 MeV protons, of dysprosium of various isotopic composition. Irradiation of Dy^{156} led to the appearance of an hourly activity yielding conversion electrons of the 138.1 keV transition ([1]).

The isotope Ho^{156} was obtained by us by irradiating tantalum with 660 MeV protons at the synchrocyclotron of the Joint Institute for Nuclear Research. The holmium fraction obtained by chromatographic separation of the rare earths was studied in works ([2,3]) and in the present work. K. Ya. Gromov et al. ([2]) established that the intensities of the K-, L-, and M-lines of the transition with energy 138 keV decrease with a period of 56 ± 2 min, and found the K-line of the 268 keV transition, whose intensity decreased with a period of 55 ± 2 min. A. S. Basina et al. ([3]), in addition to the lines of these two transitions, found conversion lines of transitions of 366 and 686 keV which, by their half-life, were also assigned to Ho^{156}. In these works it was suggested that the transitions with energies 138, 268, and 366 keV form a rotational band in Dy^{156}. N. A. Bonch-Osmolovskaya, B. S. Dzhelepov, O. E. Kraft, and Chkou Yue-Wa* studied the positron spectrum of the holmium fraction. Three components of the β^+ spectrum were found, with end-point energies 2930 ± 100, 1800 ± 50, and 1300 ± 70 keV and intensities 1, 14, and 4, respectively. The intensity decreased with a period of 53 ± 7 min. In view of the possible presence of Ho^{156}, decaying with a period of 46 ± 3 min. ([4]), it is difficult to assign these spectra to a definite isotope. In an earlier work by A. V. Kalyamin et al. ([5]), a positron spectrum was found with an end-point energy of 2.1 ± 0.15 MeV, belonging to a Ho isotope with a similar half-life.

The study of Ho^{156} was undertaken by us with the aim of refining the transition energies, determining the multipolarities, and establishing the level scheme of Dy^{156}.

Table 1 gives the experimental results of the study of Ho^{156}. We refined the value of the half-life for the 366.7 keV transition: $T_{1/2} = 57 \pm 3$ min. Direct measurement of the magnetic field in the spectrometer by means of the nuclear-resonance method made it possible to determine the transition energies with an accuracy of 0.05–0.10%. The sufficient resolution of the instrument made it possible not only to determine the ratio K/L, but also to estimate the ratio L_{I+II}/L_{III} for a number of transitions. Table 2 gives a comparison of the results obtained with theory, and the conclusion is drawn that all the transitions are of type $E2$. A small admixture of $M1$ cannot be excluded on the basis of the experimental data, but the considerations given below concerning the rotational band make it possible to accept that all three transitions are pure electric quadrupole transitions.

* Unpublished.

Table 1

Conversion lines of Ho^{156}

Line	$H\rho$	E_e	$h\nu$	Intensity, our data	Intensity, according to work ([8])
K 138.0	1017.3	84.1	137.9	1800 ± 500	1420
L_{II} 138.0	1287.5	129.4	138.0	600	1000
L_{III} 138.0	1292.3	130.2	138.1	400	1000
K 266.4	1709.4	212.6	266.4	375 ± 40	300
L_{I+II} 266.4	1915.5	257.6	266.4	89 ± 10	154*
L_{III} 266.4	1919.7	258.6	266.4	36 ± 4	154*
K 366.7	2156	312.9	366.7	37 ± 4	31
L_{I} 366.7	3343	357.6	366.7	5.6 ± 0.7	11*
L_{III} 366.7	2349	359.0	366.8	1.6 ± 0.3	11*
K 685.2	3409	631.4	685.2	23 ± 3	24

* $(L + M)$-lines.

Table 2

Determination of the multipolarities of transitions in Dy^{156}

Transition, keV	Ratio	$E1$	$E2$	$E3$	$M1$	$M2$	$M3$	Experiment	Conclusion on multipolarity
138.0	K/L	6.7	1.76	0.34	6.8	4.2	1.9	1.8 ± 0.5	$E2$*
138.0	$L_{\mathrm{I+II}}/L_{\mathrm{III}}$	5.8	1.5	1.5	7.8	7.5	1.6	1.5 ± 0.3	$E2$*
266.4	K/L	7.0	3.3	1.23	6.8	5.1	3.3	3.0 ± 0.4	$E2$
266.4	$L_{\mathrm{I+II}}/L_{\mathrm{III}}$	4.2	2.9	2.2	92	16	3.6	2.5 ± 0.6	$E2$
366.7	K/L	7.1	4.3	2.1	6.5	5.5	4.1	5.1 ± 0.8	$E2$
366.7	$L_{\mathrm{I+II}}/L_{\mathrm{III}}$	5.3	4.5	3.3	98	24	5.4	3.5 ± 1.0	$E2$

* The multipolarity $M3$ can be excluded from the ratio $L_{\mathrm{I}}/L_{\mathrm{II}}$. It is equal to 0.35 for an $E2$ transition and 11 for an $M3$ transition. According to our experimental data, it may be said that the L_{II} line is more intense than L_{I}.

Table 3

Relative intensities of transitions in Dy^{156}

Transition energy, keV	Multipolarity	α_K	I_K expt.*	I_γ	I_{trans}	Transition energy, keV	Multipolarity	α_K	I_K expt.*	I_γ	I_{trans}
138.0	$E2$	0.51	1800	3500	6600	685.2	$E1$	0.0022	23	10400	10400
266.4	$E2$	0.067	375	5600	6100	685.2	$E2$	1.0058	23	4000	4000
366.7	$E2$	0.027	37	1370	1400	685.2	$M1$	0.0115	23	2000	2000

* $\Sigma I_{L\,138.0}$ is taken as 1000.

Knowing the intensities of the conversion lines and the multipolarities of the transitions, one can determine the relative intensities of the transitions. Table 3 gives the results of the calculation of the relative transition intensities. The error in determining the line intensities is 10%. Therefore the intensities of the transitions with energies 138.0 and 266.4 keV are the same within the limits of error.

Fig. 1. Decay scheme of Ho156. In circles—the relative intensities of the transitions

Figure 1: Fig. 1. Decay scheme of Ho156. In circles—the relative intensities of the transitions

On the basis of the results obtained one can draw certain conclusions about the level scheme of Dy^{156}. This scheme is shown in Fig. 1. The four lowest states apparently form a rotational band. However, the ratio of energies $E_{6+} : E_{4+} : E_{2+} = 5.59 : 2.93 : 1$ differs strongly from the ratio $7 : 3.33 : 1$ predicted by the Bohr and Mottelson theory. The introduction of corrections for the change in deformation during rotation, or the displacement of levels owing to the proximity of other states with equal spins, cannot appreciably improve the situation. The deviations from the simple rotational formula are not surprising, however, since the nucleus ${}_{66}Dy_{90}^{156}$ lies near the boundary of the region of deformed nuclei. In other nuclei lying near the boundaries $N = 90$ or $N = 114$, the deviations have a similar character, for example: Sm^{152} ($N = 90$) $3.00 : 1$; Gd^{154} ($N = 90$) $5.84 : 3.16 : 1$; Os^{190} ($N = 144$) $5.62 : 2.94 : 1$.

The energy of the first excited level of these nuclei is also considerably larger than in ordinary deformed nuclei: Sm^{152} 122 keV; Gd^{154} 123 keV; Os^{190} 187 keV.

Fig. 1. Decay scheme of Ho^{156}. In the circles—the relative intensities of the transitions

Let us now consider the transition with energy 685.2 keV. It clearly does not belong to the rotational band and, by analogy with neighboring even-even deformed nuclei, is most likely a transition from upper levels to the lower rotational band. If it led directly to the ground state, this would mean that there exists a level with the same energy and with a small spin $I \leqslant 2$. Population of such a level by electron capture in Ho^{156} is unlikely. If the transition led to the 2^+ level, the transition with energy 138.0 keV would be appreciably more intense than the transition with energy 266.4 keV, and this is not observed. If the 685.2-keV transition went to the 6^+ level or to higher rotational levels, then the transition with energy 366.7 keV would be more intense. Therefore we assume that the transition under consideration proceeds to the rotational level 4^+. This determines the energy of the new level as 1089.6 keV. From the ratio of the transition intensities it is clear that the decay of Ho^{156} often leads to the 4^+ and 6^+ levels and rarely to the 2^+ level. This means that the spin of Ho^{156} is large, in any case greater than 3. The generalized model of nuclear shells predicts the characteristic 5^- (the 67th proton is in the state [523] $7/2^-$, the 89th neutron in the state [651] $3/2^+$). Although for the β-decay of Ho^{156} to the levels 404.4 keV (4^+) and 771.1 keV (6^+) $\Delta I = 1$, it does not seem probable to us that a substantial fraction of the decays proceeds through these channels, because of the large forbiddenness in the quantum number K. It is more likely that the decay of Ho^{156} leads for the most part to highly excited levels having spin 4, 5,

or 6. The 1089.6-keV level may be one of these levels. It should be noted that in the decay of Ho^{156} excitation of high-lying levels of Dy^{156} is possible, since the ener-

The decay energy of Ho^{156} is, according to semiempirical formulas, more than 4 MeV (Fig. 1).

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Note: Figure translations are in progress. See original paper for figures.