SOVIET PHYSICS JETP VOLUME 34(7), NUMBER 6 DECEMBER, 1958

ENERGY LEVELS OF Dy^{161}*

S. A. BARANOV, Iu. F. RODIONOV, G. V. SHISHKIN, and L. V. CHISTIAKOV

Submitted to JETP editor March 13, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **34**, 1367-1380 (June, 1958)

The decay of beta-active Tb^{161} was studied using a double focusing magnetic β-spectrometer, a proportional counter spectrometer and a scintillation spectrometer. The results of the investigation enable us to establish the existence of the following γ-transitions Dy^{161}: 25.6 (E1); 25.8 (E1); 27.7; 42; 48.9 (M1); 52; 57.6; 74.5 (E1); 103.8; 131.5 kev. Gamma ray transitions with E_γ = 20.4, 23.1, 46.3, 53.2, 57.0, 78.3, 84.0, 105.8 and ~275 kev were established less reliably. In studying the decay of Tb^{161}, we also observed groups of β-particles with endpoints E_{01} = 540 kev, E_{02} = 465 kev, (E_{03} = 415 kev), and $E_{04} \approx$ 215 kev. On the basis of the experimental data, a possible energy level scheme is proposed for Dy^{161}.

1. INTRODUCTION

RADIOACTIVE Tb^{161} decays by beta emission to stable Dy^{161}. The half-life of Tb^{161} is 7.2 days. Some information concerning the radiations emitted in the decay of this nucleus and about the levels of Dy^{161} has been given in several quite incomplete papers.[1-8]

In 1956, Cork et al.[9] and Smith et al.[10], using scintillation and β-spectrometers, studied the decay of Tb^{161} in more detail, and constructed different level schemes for Dy^{161}. These investigations still did not enable one to resolve certain discrepancies in the decay scheme of Dy^{161}. We therefore undertook a further more careful investigation of both the electron spectrum, including its low-energy part ($E_{\text{conv. min}}$ = 3 kev), and the soft γ-radiation occurring in the decay of Tb^{161}.

2. APPARATUS AND PREPARATION OF RADIOACTIVE Tb^{161} SOURCE

For our investigation of the electron spectrum of Tb^{161}, we used a magnetic β-spectrometer with $\pi\sqrt{2}$ double focusing.[11] The resolving power of the spectrometer was 0.3%, with a solid angle equal to 0.4% of 4π. The Tb^{161} source used here was deposited on a thin organic backing (thickness 10^{-5} cm) and had dimensions 1.5×25 mm^2.

To study the γ-radiation accompanying the Tb^{161} decay, we used proportional-counter spectrometers filled with mixtures of $A + CH_4$, $Kr + CH_4$, and $Xe + CH_4$, and a scintillation spectrometer with a NaI (Tl) crystal. These experiments were done with another Tb^{161} source, whose absolute decay rate had previously been measured with a 4π-counter[12] operating in the region of limited proportionality. The various equipments were calibrated using well-known electron and γ-ray lines of Am^{241} (references 13 and 14), Cs^{137}, and Na^{22}.

The Tb^{161} sample was obtained from the reaction: $Gd^{160}(n\gamma)Gd^{161}\xrightarrow[3.7\text{ min}]{\beta^-}Tb^{161}$. The starting material was gadolinium, enriched to 99.9% in the Gd^{160} isotope. The Gd^{160} sample was irradiated with thermal neutrons in the RFT reactor for a period of seven days. The irradiated sample was dissolved in dilute HCl and then the rare earths were precipitated out as fluorides using HF. The hydroxide residue was dissolved in a minimal amount of 0.1 N HCl, and the solution was transferred to a column of Dowex-50 resin. The chromatographic separation was carried out with 0.4 N lactic acid having pH = 4.3 using the method described by Thompson et al.[15] The eluate fraction corresponding to the terbium peak on the chromatogram was dried, and the residue was heated and dissolved in HCl. The twice-normal (with respect to HCl) solution which was obtained was deposited on an organic backing. After drying, $TbCl_3$ was left on the plate.

For the β-spectrometer studies, we first deposited a small (1.5×25 mm^2) semi-transparent strip of aquadag on the organic backing. The aquadag guaranteed that the source wetted the backing and had the necessary conductivity. The Tb^{161} sample prepared in this way had a surface density of about 5 micrograms/cm^2.

Since the thickness of the film over the window of the β-detector in the β-spectrometer was $\sim 10^{-5}$ cm, this together with the source just de-

---

*This work was reported at the eighth All-Union Conference on Nuclear Spectroscopy (Leningrad, January, 1958).

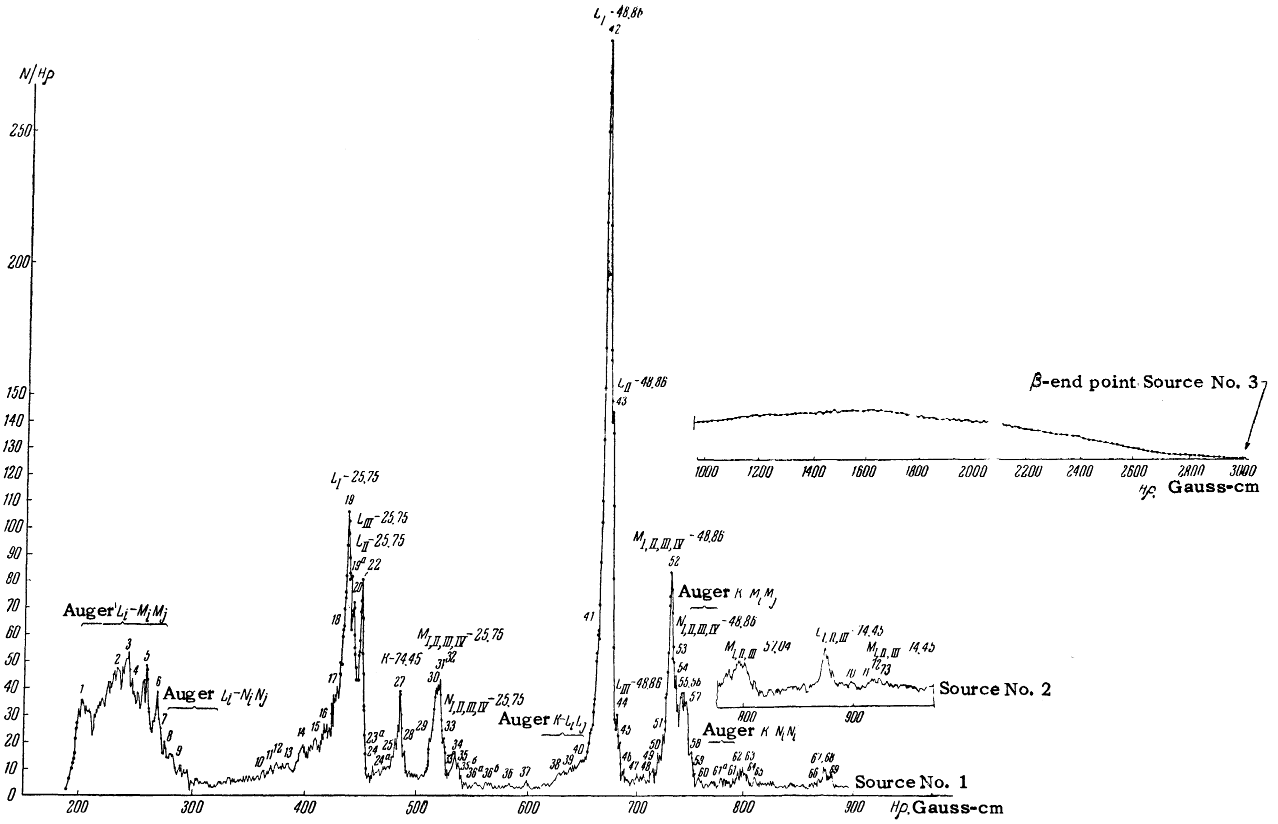

FIG. 1. Electron Spectrum of Tb^{161}.

scribed enabled us to study the electron spectrum down to very low energies.

3. EXPERIMENTAL RESULTS

(a) β-Spectrometer Measurements

Figure 1 shows a large part of the β-spectrum (source #3) and electron spectrum of Tb^{161} in the range of Hρ values from 200 to 900 Gauss-cm as obtained with the thin source (surface density 5 microgm/cm), and in the interval of Hρ values from 780 to 980 Gauss-cm, as gotten with a more intense source (#2).

The tens of electron lines observed by us, which, as we see from Fig. 1, are primarily in the low-energy part of the spectrum, and the absence of even weak high energy conversion lines would seem to justify the assumption that almost all of the energy levels of Dy^{161} are located in the energy interval from 0 to 132 kev. Analysis of individual parts of the electron spectrum enabled us to show that in this nucleus there are γ-transitions with only slightly different energies. As an example of this statement, a portion of the spectrum is shown in Fig. 2 in which there are clearly visible the L-conversion lines (19, 20, 22) of the known γ-transition with energy 25.75 kev (cf. for example Ref. 10), and the L-lines of an unknown γ-transition with $E_\gamma = 25.6$ kev (lines 18, 19a, 21). The dotted lines in the Figure are the L_{II} and L_{III} lines of $E_\gamma = 25.75$, as obtained by graphical resolution. One can apparently also assert the existence of a γ-transition with $E_\gamma \approx 23.1$ kev (cf. Table I and Fig. 1, peaks 14, 15, 16).

Table I gives the interpretation of the conversion lines corresponding to γ-transitions in Dy^{161} as well as the intensities for some of the lines. In the last column we give the multipolarities of the tran-

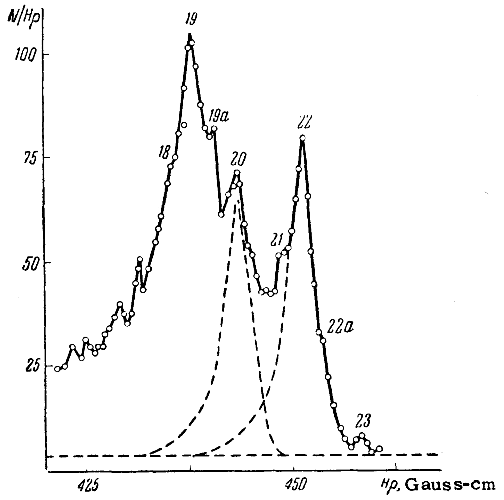

FIG. 2. Portion of the electron spectrum of Tb^{161}.

TABLE I. Interpretation of Electron Lines from Decay of Tb^{161}

Line number	Observed electron energy, kev	Conversion	E_γ, kev	Intensity in arbitrary units	Remarks
1	2	3	4	5	6
10	11.4	L_I	20.45		
11	11.8	L_{II}	20.39	0.7	
12	12.15	L_{III}	20.20		
23	18.35	M_I	20.38		
23a	18.50	M_{II}	20.35		or $L_I - 27.7$
24	18.65	M_{III}	20.33		
			av. 20.35*		
14	14.11	L_I	23.16		
15	14.55	L_{II}	23.14		
16	15.25	L_{III}	23.05		
			av. 23.12*		
18	16.55	L_I	25.60		
19a	17.00	L_{II}	25.59	19.1	
21	17.85	L_{III}	25.55		
			av. 25.58		(E 1)
19	16.80	L_I	25.85	(23.2)	Calculated
20	17.25	L_{II}	25.84	18.00	
22	17.85	L_{III}	25.65	22.7	
30	23.70	M_I	25.74		The value of I_M is the sum of $I_M(25.75) + I_M(25.58)$
31	23.85	M_{II}	25.70		
32	24.10	M_{III}	25.78	24.6	
33	24.35	M_{IV}	25.69		
34	25.35	N_I	25.77		Cf. I_M or $M - 27.7$
35	25.60	N_{IV}	25.77	5.6	
			av. 25.75		E 1
24	18.65	L_I	27.70		
24a	19.15	L_{II}	27.74		
25	20.00	L_{III}	27.80		
35	25.60	M_I	27.63		
35b	25.90	M_{II}	27.75		
36a	27.10	N_I	27.52		
36b	27.45	N_{II}	27.78		
			av. 27.70		
37a	33.60	L_I	42.65		
37b	34.10	L_{II}	42.70		
37c	34.90	L_{III}	42.75		
			av. 42.70		
40	37.65	L_{II}	46.24		
41	38.25	L_{III}	46.30		
			av. 46.27		E 2 (?)
42	39.85	L_I	48.90		
43	40.30	L_{II}	48.89	177.0	
44	41.00	L_{III}	48.80		
52	46.80	M_I	48.84		
53	47.00	M_{II}	48.85	37.7	
54	47.20	M_{III}	48.88		
57	48.45	N_I	48.87		
			av. 48.86		M 1
47	43.00	L_I	52.05		
48	43.80	L_{II}	52.39		
			av. 52.22*		
49	44.6	L_{II}	53.20		
50	45.3	L_{III}	53.10		
			av. 53.15*		
55	48.00	L_I	57.05		
57	48.45	L_{II}	56.94		or $L_I - 57.55$
58	49.10	L_{III}	56.90		or $L_{II} - 57.7$
63	55.00	M_I	57.04		
64	55.30	M_{II}	57.15		
65	56.65	N_I	57.05		
			av. 57.04		
1	3.7	K	57.7		
57	48.45	L_I	57.55		or $L_I - 57.05$
58	49.10	L_{II}	57.69		or $L_{III} - 57.05$
			av. 57.64		
27	20.75	K	74.52	12.6	
67	65.45	L_I	74.50		
68	65.85	L_{II}	74.44	3.9	
69	66.35	L_{III}	74.35		
71	72.35	M_I	74.40		
72	72.65	M_{II}	74.50		
73	72.80	M_{III}	74.48		
			av. 74.45		E 1
36	30.25	K	83.9		
			av. 83.9		
60	50.0	K	103.77		
			av. 103.77		
61a	52.0	K	105.77		
			av. 105.77		
	77.7	K	131.47		
			av. 131.47**		

---

*Another interpretation of the electron lines is not excluded.

**Observed using Pb as converter with a very strong Tb^{161} source.

sitions, as determined from the experimental data. It should be noted that the identification of individual lines is not unique, and certain of the lines are not given in the table.

In the Kurie plot (cf. Fig. 3) constructed from the experimental data, one can resolve four partial spectra with end points respectively equal to E_{01} = 540 ± 5 kev, E_{02} = 465 kev, E_{03} = 410 kev and E_{04} = 215 kev. The portion of the β-spectrum corresponding to β-particle energies above 500 kev was taken very carefully with three different sources. However, we did not observe the partial β-spectrum with end point 570 kev which was reported by Smith et al.[10] Since the method of resolution of a Kurie plot into individual components is very inexact, as we shall show later the possibility is not excluded that there are additional partial β-spectra with end point energies of 515 and 490 kev, as were reported in reference 10.

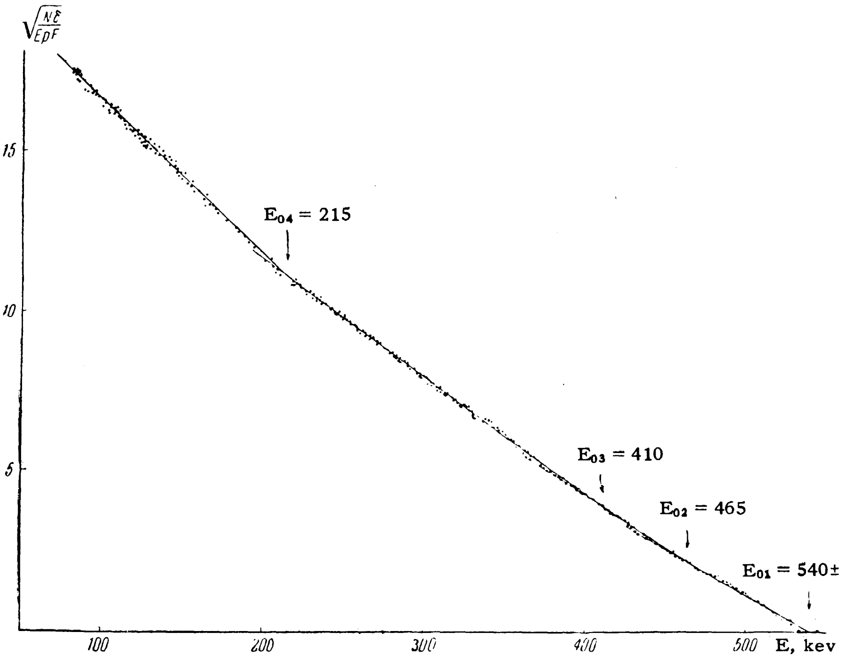

FIG. 3. Kurie plot of β-spectrum of Tb^{161}; N is the number of particles recorded, E is the total energy of the β-particles; F, p, ƃ are tabulated functions from β-decay theory.

Summarizing the experimental data presented here, we may conclude that the decay of Tb^{161} shows a complex β-spectrum, consisting of at least 4 to 6 partial β-spectra having (except for $E_{04} \approx$ 215 kev) only slightly different end points. Together with the large number of low energy γ-transitions observed in Dy^{161} (cf. Table I), this indicates the existence of a large number of energy levels close to the ground state in Dy^{161}.

(b) Measurements with the Proportional Counter Spectrometer and Gamma Spectrometer

The use of proportional counters for studying x-rays and soft γ-radiation has a variety of advantages over the use of a scintillation γ-spectrometer. This is especially true with regard to resolving power, which is the fundamental characteristic of such equipment. The investigation of the γ-spectrum in the energy interval 2 to 130 kev was therefore done only with such counters, filled with mixtures of the following gases: A + CH_4, Kr + CH_4, and Xe + CH_4. A scintillation spectrometer with a NaI (Tl) crystal was used to study the spectrum of γ-rays with $E_\gamma > 130$ kev.

Combined with these detectors we used an unsaturated linear amplifier and multi-channel pulse-amplitude differential analyzers. One of these had 150 channels, and was constructed under the direction of, and according to the design of Tsytovich.[16] The shape of the low energy spectrum of x-rays and γ-radiation was reproduced on a linear scale on one of the oscillograph tubes (diameter 300 mm) of this analyzer.

Figure 4 shows the spectrum of x-rays and soft γ-radiation from Dy^{161} in coordinates (N, $E_{x,\gamma}$), where N is the number of pulses and $E_{x,\gamma}$ is the energy of the x-ray or γ-ray in kev, for three different series of measurements. The data from which these curves were constructed were not corrected for the negligible background or for the variation of counting efficiency with γ-ray energy E_γ.

The use of a Kr + CH_4 counter filling in the first series and of Xe + CH_4 in the other two sets enables us clearly to separate the main x-ray and γ-ray lines and to eliminate the so-called satellite

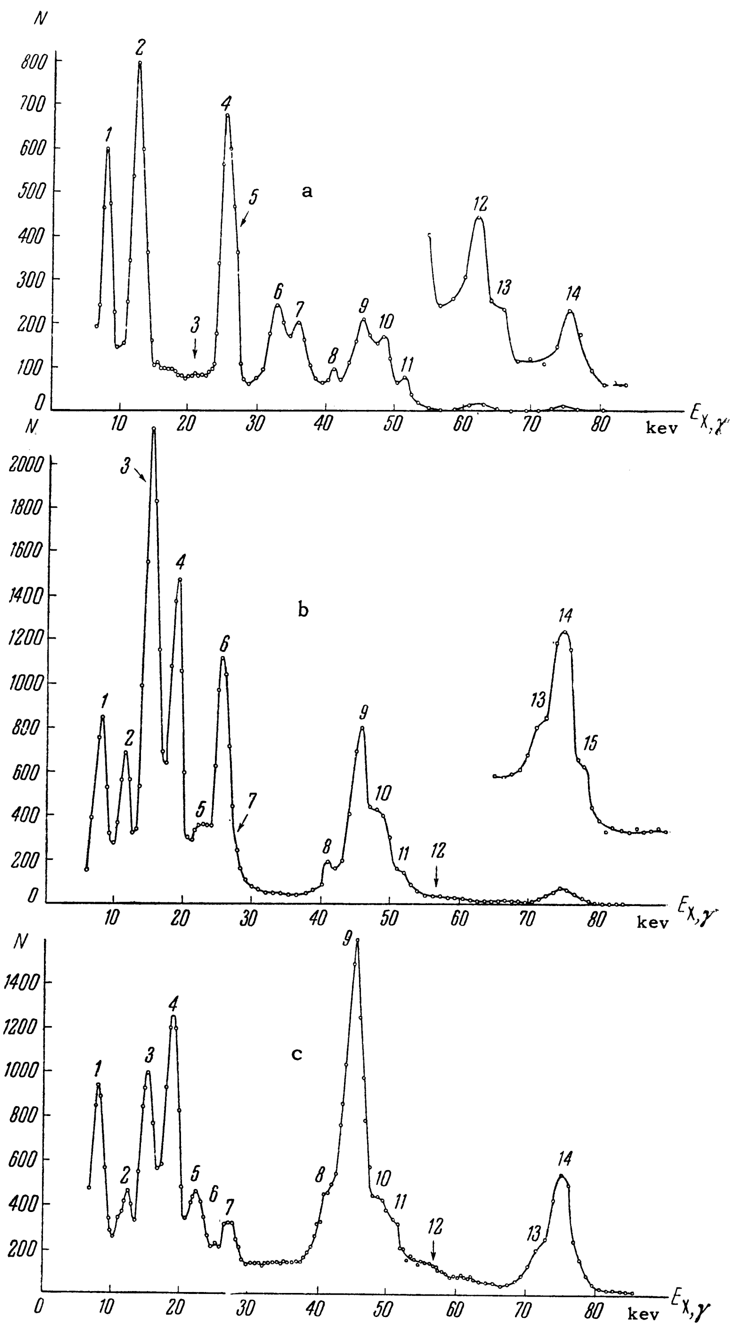

FIG. 4. X-rays and soft γ-radiation from Dy^{161}: (a) counter filled with Kr + CH_4 mixture, (b) and (c) counter filled with Xe + CH_4 mixture; (a) and (b) – 2 mm Al Absorber, (c) – 1 mm Cu absorber

peaks.* From a comparison of Figs. 4a and 4b, for example, we easily see that lines 2, 6, 7, 12, and 13 (Fig. 4a) are satellite peaks. Figure 4c shows the same spectrum with a 1 mm thick copper absorber placed between the source and the end window of the proportional counter. This experiment enabled us to establish with certainty the presence of the two seemingly doubtful satellite peaks 5 and 7. These lines have a complex shape. Consequently the possibility is not excluded that there are four γ -rays corresponding to them, with energies of approximately 52, 53, 57, and 57.6 kev. This statement is not in contradiction with the data given in Table I. A similar conclusion can apparently be drawn concerning peak 2 of Fig. 4c.

The detailed interpretation of the observed γ -ray lines shown in Figs. 4a and 4b is given in Table II. The intensities of individual γ -lines are given in percent in the last column. In this case corrections were made for background and for the effi-

---

*The absorption of low energy γ-quanta in a counter filled with a heavy gas occurs via the photoeffect. If the characteristic x-radiation of the gas atoms is not recorded by the counter, then in addition to the main line ($E_0 = E_\gamma$) there will appear a satellite line, having energy $E = E_\gamma - E_{K\alpha}$. Here E_γ is the energy of the γ-quanta entering the counter, and $E_{K\alpha}$ is the energy of the $K\alpha$-radiation of the atoms of the gas in the counter.

TABLE II

	Counter filling ($Kr + CH_4$)		Counter filling ($Xe + CH_4$)		
Line No.	Energy $E_{X,\gamma}$, kev	Interpretation of line	Energy $E_{X,\gamma}$, kev	Interpretation of line	Intensity in %
1	8.0 ± 0.1	E_X of counter wall material	8.0 ± 0.1	E_X of counter wall material	
2	12.6 ± 0.1	E_S^* from sum of $E_\gamma = 25.75$ and $E_\gamma = 25.58$ kev	12.0 ± 0.2	E_S of $E_\gamma = 41.5$ kev	
3	21 ± 0.2	E_γ (?)	15.5 ± 0.3	E_S of $E_X = 45$ kev	
4	25.5 ± 0.3	sum of $E_\gamma = 25.75$ and $E_\gamma = 25.58$ kev	19.3 ± 0.3	E_S of $E_\gamma = 49$ kev	
5	27.0 ± 0.3	E_γ	22.5 ± 0.3	E_S of $E_{X,\gamma} = 52$ kev	
6	32.5 ± 0.3	E_S of $E_X = 45$ kev	25.5 ± 0.3	sum of $E_\gamma = 25.75$ and 25.58 kev	26.3 ± 3
7	36.5 ± 0.3	E_S of $E_X = 49$ kev	27.0 ± 0.3	sum of E_γ and E_S of $E_\gamma = 57$ kev	
8	41.5 ± 0.3	$E_\gamma + E_S$ of $E_{X,\gamma} = 52$ kev	41.5 ± 0.3	sum of E_γ and E_S of $E_\gamma = 72$ kev	9.9 ± 1
9	45.0 ± 0.3	E_X	45 ± 0.3	sum of E_X and E_S of $E_\gamma = 75$ kev	
10	49.0 ± 0.3	E_γ	49.0 ± 0.3	sum of E_γ and E_S of $E_\gamma = 78$ kev	42 ± 4
11	52.0 ± 0.3	$E_{X,\gamma}$	52.0 ± 0.3	$E_{X,\gamma}$	
12	62.5 ± 0.4	E_S of $E_\gamma = 75$ kev	57.0 ± 0.3	E_γ	4.4 ± 0.5
13	65.0 ± 0.5	E_S of $E_\gamma = 78$ kev	72.0 ± 0.5	(E_γ and E_S) of $E_\gamma = 102$ kev?	2.6 ± 0.5
14	75.0 ± 0.5	E_γ	75.0 ± 0.5	E_γ	8.6 ± 0.9
15	78.0 ± 0.5	E_γ ?**	78.0 ± 0.5	E_γ?*	5.9 ± 0.6

*E_S denotes a satelite line.

**Part of the equipment using the proportional counter was shielded with lead, so that the 78-kev γ-ray line can be assigned to the characteristic Pb radiation.

TABLE III. Energy (in kev) of γ-transitions in Dy^{161}

This paper	Cork et al.[9]	Smith et al.[10]	This paper	Cork et al.[9]	Smith et al.[10]	Remarks
20.35			57.04		56.9±0.4	
23.12			57.64	57.3		
25.58			74.45	74.8	74.6±0.4	
25.75	25.6	25.5±0.1	78.11?	78.3		Low probability of existence
27.70	27.7		83.90			
42.70			103.77			
46.27			105.77	106.2		
48.86	48.9	48.9±0.1	131.5	132.1		
52.22			~275*			
53.15						

*These γ-rays were observed in a scintillation spectrometer with a very strong source.

ciency of recording of γ-rays of different energies by the counter filled with the $Xe + CH_4$ mixture.

An examination of the data of Table II shows that some of the γ-lines are masked by the satellite peaks of γ-quanta of higher energy. However, in the majority of cases, simultaneous analysis of the results of the measurements with the β-spectrometer and the proportional counters makes it possible to eliminate the uncertainty. The γ-lines corresponding to γ-ray energies of 72 and 78 kev are peculiar. These lines cannot be interpreted uniquely, and their existence remains an open question.

Table III summarizes the data concerning γ-transitions in Dy^{161}, as found in the present work and in Refs. 9, 10. These data will be used later

TABLE IV. Absolute Conversion Coefficients η for γ-rays of Dy^{161}

E_γ, kev	$\frac{E_\gamma}{m_0 c^2}$	Experimental values of η		Theoretical values of η						Multipolarity
		A_K/B	$A_{\Sigma L}/B$	$E1$		$E2$		$M1$		
				η_K	$\eta_{\Sigma L}$	η_K	$\eta_{\Sigma L}$	η_K	$\eta_{\Sigma L}$	
25.75	~0.05		0.98±0.18		1.79		85.41		17.9	$E1$
48.86	~0.10		1.72±0.30		0.261		25.96*		2.30	$M1$
					0.266*				2.14*	
74.45	~0.15	0.46±0.10		0.56	0.083	2.82	2.57	4.45	0.71	$E1$
				0.52*	0.088*	1.97*	2.41*	4.37*	0.65*	

*These are theoretical conversion coefficients calculated by Sliv, taking into account the finite size of the nucleus and screening by the atomic electrons. The remaining values of η were obtained by interpolation in Rose's tables.[17]

in the paper to construct the level scheme of Dy^{161}.

4. DETERMINATION OF MULTIPOLARITY OF GAMMA-TRANSITIONS

The measurements which were done only with the β-spectrometer enable us quite definitely to assign the multipolarity of the 25.75 kev γ-transition. For this case, $(L_{II}/L_{III})_{exp} = 0.793$. The theoretical values of this ratio for E1, E2, and M1, respectively, are 0.781, 1.424, and 7.000. Thus the 25.75 kev γ-line can be assigned to be electric dipole. From the data presented in Table I and Fig. 1, one might also conclude that the multipolarities of the γ-quanta with $E_\gamma = 48.86$ and $E_\gamma = 74.45$ kev must be M1 and E1, respectively. This conclusion is not certain, especially for the second case. We therefore chose a different way of determining the multipolarity of the γ-radiation, based on the determination of absolute conversion coefficients from the experimental data.

As we said earlier, the measurements of the γ-radiation of Dy^{161} with a proportional counter were done using a source whose absolute β-activity had been determined using a 4π counter. After introducing the appropriate corrections, this enabled us to determine the quantity B, i.e., the number of γ-quanta of the given energy accompanying a single β-emission. The results with the β-spectrometer, in turn, enabled us to determine the other essential quantity A — the number of K-, L- or M-electrons (for a given E_γ) which accompany a single β-decay. The ratio $\eta = A/B$ of these two quantities is the absolute conversion coefficient. By comparing the experimental and theoretical values, we established the multipolarities of some of the γ-transitions.

In Table IV we give the experimental values of the absolute conversion coefficients for the 25.75, 48.9 and 74.5 kev γ-rays. The right half of the table gives the theoretical values of η for various multipolarities. The assigned multipolarities of the γ-transitions are given in the last column.

It is easy to see from Table IV that the γ-radiations with energy 48.9 and 74.5 kev should be assigned respectively to magnetic and electric dipole. The disagreement between the theoretical and experimental values of η (for E1) for $E_\gamma = 25.8$ kev cannot be explained by the inaccuracy of the theoretical values or by the large experimental errors.

As we showed earlier (cf. Fig. 2 and Table I), there are two γ-transitions in Dy^{161} with almost equal energies $E_\gamma = 25.75$ and 25.58 kev. In studying the γ-spectrum with a proportional counter, it is not possible to separate these two lines. Therefore γ-line 6 in Fig. 4a (and the corresponding line 4 in Fig. 4b) is the sum of these two γ-lines. If we take account of this fact, the value of B should be somewhat lower for $E_\gamma = 25.75$ kev than the value used for the calculation of $\eta_{\Sigma L} = A_{\Sigma L}/B$. Consequently, $\eta_{exp} = A_{\Sigma L}/B$ is in this case close to the theoretical value $\eta_{\Sigma L} = 1.79$ (for E1 radiation) given in Table IV. It is not difficult to show by a simple calculation that the γ-ray with $E_\gamma = 25.56$ kev is electric dipole.

5. DISCUSSION OF RESULTS; LEVEL SCHEME FOR Dy^{161}

There are many difficulties in constructing a level scheme for Dy^{161} from the experimental data. As we said earlier, the β-spectrum of Tb^{161} is complex, and consists of 4 to 6 partial β-spectra whose end points differ very little from one another. The construction of these spectra from the Kurie plot and the estimate of their intensity is very inaccurate.

With the present accuracy of the experiment, the interpretation of certain of the conversion and γ-ray lines is not unique, which also complicates the setting up of a level scheme for Dy^{161}. In this connection it is not without interest to remark that even the apparently definitely established γ-lines with energies 25.7 and 48.9 kev (cf. for example Ref. 10) are complex, each consisting of two components. This assertion is obvious for the case of $E_\gamma = 25.7$ kev (cf. Fig. 2). The proof of the assertion for the 48.9 kev line follows from the fact that the halfwidth $\xi_{49} = \Delta H\rho/H\rho$ of the $L_I - 48.9$ line is somewhat greater than the halfwidth ξ_{75} of the K – 74.5 line.* According to our estimates, the second component E'_γ has an energy ~ 0.2 kev less than the main γ-line which is several times more intense. It should be mentioned that we are at the limit of our experimental accuracy, which reduces the rigor of this proof. However, as we shall see later, this interpretation is supported by other experimental facts.

Using the energy values for these four γ-quanta, it is easy to see that the sums (25.75 + 48.70) and (25.58 + 48.86) kev coincide precisely with $E_\gamma = 74.45$ kev. Consequently, the γ-rays with energies 25.75 and 25.58 kev are, respectively, in cascade with the 48.70 and 48.86 γ-quanta.

Using the data of Table I, it is not hard to show that the 74.5 kev transition, which is equal to the energy difference of two partial β-spectra ($E_{01} - E_{02}$) is a direct transition to the ground state of Dy^{161}. Thus there must also be levels at 25.8 and 48.9 kev between the ground state of this nucleus and the level at 74.5 kev.

If we make use of the experimental values of the intensities $I = N_{l_k} + N_\gamma$ of the γ-transitions, it can be shown that $I_{74.5} \approx 35$, $I_{48.9+48.7} \approx 250$, $I_{25.8} \approx 100$, and finally $I_{25.6} \approx 30$ (intensities in arbitrary units). These data show that in the β-decay of Tb^{161} there is also a β-transition to the 48.9 kev level, and possibly also to the 25.8 kev level in Dy^{161}. The end point of the first partial β-spectrum is ~ 490 kev, and that of the second ~ 514 kev. As was stated earlier (cf. Section 3a), this is not contradicted by the data of Smith et al.[10] In addition, the γ-ray at 131.5 kev, the cascade γ-rays with energies $E_\gamma = 74.5$ and 57.0 kev, and the observed partial β-spectrum with end point $E_{03} = 410$ kev indicate the existence of a level at 131.5 kev. From the data of Tables I and III it also follows that there should be levels at 103.8 and ~ 325 kev.

It is clear that we have by no means used all of the experimental data in this analysis. Apparently, in addition to those given above, there are levels of Dy^{161} which manifest themselves weakly in the β-decay of Tb^{161}.

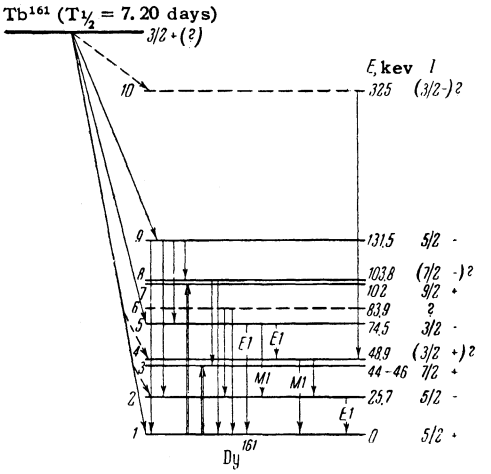

FIG. 5. Level Scheme of Dy^{161}.

There are statements in the literature that Pieper and Heydenburg[18] have repeated their experiments on Coulomb excitation of dysprosium, using enriched isotopes. Similar experiments have also been done very recently by Elbeck, Nielsen and Olsen.* According to these investigators, the first two levels of the ground rotational band of Dy^{161} are located at distances of (46 — 44) and (103 — 102) kev from the ground state, which has a spin $I_0 = 5/2$.[19,20]

The 44 and 102 kev levels scarcely appear in the β-decay of Tb^{161}. Some indications for the 44 — 46 kev level can be found from our data (cf. Table I and Fig. 1). There may be a very weak L-46 conversion line in this energy range, which is masked by the K-LL Auger electrons. The 103.8 kev γ-transition mentioned earlier could also be a proof of the existence of the 102 kev level. However this is unlikely, since the observed γ-ray of energy 27.7 = (131.5 – 103.8) kev can hardly be assigned to be magnetic quadrupole or E3 radiation (cf. the level scheme in Fig. 5).

Summarizing our discussion, we conclude that the following energy levels of Dy^{161} are established: 25.8, 44 — 46, 74.5, 84?, 102, 103.8, 131.5, ~ 325 kev.

In Fig. 5 we show a possible level scheme for Dy^{161} constructed from the experimental data. The spin assignments are shown at the right. The levels are designated by the numbers given on the left. Levels 3 and 7 belong to the ground rotational band, which is associated with collective motion of the

---

*The analysis was carried out for four series of measurements of the K-74.5 and $L_I - 48.9$ conversion lines from different sources.

*This work was done at the Institute for Theoretical Physics of Copenhagen University in 1957 (Private communication).

nucleons in the nucleus. Levels 2 and 5 are due to single particle excitation. Levels 8 and 9 are apparently terms of the rotational bands based on levels 2 and 5. Levels 4, 6 and 10 are not completely established, and their nature remains an open question.

The proposed scheme does not pretend to be conclusive. Certain similarities with this scheme can be found from the theoretical computations of Nilsson[21] and Mottelson and Nilsson.[20]

In conclusion we should mention that we have not given the log $f\tau$ values of the various γ-transitions, because these quantities cannot be determined accurately from the experimental data. The log $f\tau$ value is approximately 6 to 7. We should also mention that the half life of Tb^{161}, as determined using a 4π counter, was $T_{1/2} = (7.20 \pm 0.07)$ days. This value is in good agreement with the value of $T_{1/2}$ given in the short note of Cork et al.[9]

We are very grateful to G. Ia. Shchepkin for preparing the pure Gd^{160} isotope, and to S. N. Belenkii and R. M. Polevoi for assistance in this work.

We should like to thank P. E. Nemirovskii, A. I. Baz', V. M. Strutinskii, L. K. Peker and D. F. Zaretskii for participating in discussion of this work. We are also greatly indebted to L. A. Sliv for providing us with new values of the L-subshell conversion coefficients.

Note added in proof (May 24, 1958).
After this paper went to press, one of us (S.A.B.) received from the Institute for Theoretical Physics of Copenhagen University two preprints of papers on the levels of Dy^{161}. The experimental study of the Tb^{161} decay was done by a group of authors (P. G. Hansen, O. Nathan, O. B. Nielsen, R. K. Sheline), and the theoretical work by D. R. Bes.

The main results of these papers are in agreement with the results presented in our paper. However, there is a considerable discrepancy between the estimates of the intensity of the γ-rays with E_γ = 25.7 and 48.9 kev. This discrepancy is apparent from the following data:

Ratio of intensity of γ-transitions	Cork et al.[9]	Smith et al.[10]	Baranov et al.	Hansen et al.
I_{26}/I_{49}	2.1	0.6	0.4	1.0

The discrepancy apparently arises from inaccuracy in determining the intensity of the 25.7 kev γ-transition.

This question is of vital importance for the construction of the Dy^{161} level scheme, and requires more careful checking. Unfortunately, the experimental curves in the low-energy region of the electron spectrum are given only by Smith et al.[10] and in the present paper.

---

[1] Krisberg, Pool, and Hibdon, Phys. Rev. **74**, 44 (1948).

[2] F. D. S. Butement, Phys. Rev. **75**, 1276 (1949).

[3] B. H. Ketelle, Oak Ridge Report, cited in Hollander, Perlman and Seaborg, Revs. Mod. Phys. **25**, 469 (1953).

[4] Scharff-Goldhaber, der Mateosian, McKeown, and Sunyar, Phys. Rev. **78**, 325 (1950).

[5] R. E. Hein and A. F. Voigt, Phys. Rev. **79**, 783 (1950).

[6] Cork, LeBlanc, Nester, and Stumpf, Phys. Rev. **88**, 685 (1952).

[7] R. Barloutaud and R. Ballini, Compt. rend. **241**, 389 (1955).

[8] N. P. Heydenburg and G. M. Temmer, Phys. Rev. **100**, 150 (1955).

[9] Cork, Brice, Schmid, and Helmer, Bull. Am. Phys. Soc., Ser. II, **1**, 297 (1956).

[10] Smith, Hamilton, Robinson, and Langer, Phys. Rev. **104**, 1020 (1956).

[11] Baranov, Malov, and Shliagin, Приборы и техника эксперимента (Instr. and Meas. Eng.) **1**, 1 (1956).

[12] S. A. Baranov and R. M. Polevoi, Приборы и техника эксперимента (Instr. and Meas. Eng.) **3**, 32 (1957).

[13] S. A. Baranov and K. N. Shliagin, Тр. сессии АН СССР по мирному использованию атомной энергии. Отделение физ.-мат. наук. (Reports of the Session of the Academy of Sciences of the U.S.S.R. on Peaceful Uses of Atomic energy. Division of Physical and Mathematical Sciences) p. 251, 1956.

[14] Hollander, Smith, and Rasmussen, Phys. Rev. **102**, 1372 (1956).

[15] Thompson, Harvey, Choppin, and Seaborg, J. Amer. Chem. Soc. **76**, 6231 (1954).

[16] A. P. Tsytovich, Приборы и техника эксперимента (Instr. and Meas. Eng.) **5**, 118 (1957).

[17] Beta- and Gamma-Ray Spectroscopy, ed. by K. Siegbahn, Amsterdam, 1955.

[18] N. P. Heydenburg and G. F. Pieper, Phys. Rev. **107**, 1297 (1957).

[19] A. H. Cooke and J. G. Park, Proc. Phys. Soc. **A69**, 282 (1956).

[20] B. Mottelson and S. G. Nilsson, Phys. Rev. **99**, 1615 (1955).

[21] S. G. Nilsson, Kgl. Danske Videnskab. Selskab Mat.-fys. Medd. **29**, No. 16 (1955).

Translated by M. Hamermesh
285