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LOW ENERGY GAMMA TRANSITIONS IN Tm^{169}

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A magnetic β-spectrometer was used to study the electron spectrum of Yb^{169} in the energy range from 3 — 70 kev. The conversion lines which were found have the following relative intensities: (a) for the 8.32 kev γ-transition, $M_I : M_{II} : M_{III} : M_{IV} = 1 : 0.42 : 0.48 : 0.10$; (b) for the 20.65 kev γ-transition, $L_I : L_{II} : L_{III} = 1 : 0.14 : 0.03$; $M_I : M_{II-V} = 1 : 0.2$. The multipolarity of the 8.32 kev transition is shown to be M1 + E2 ($< 3\%$), while the 20.65 kev transition is M1.

In a series of papers[1–5] on the structure of the energy levels of Tm^{169} it was shown that the experimental spectrum essentially coincides with the theoretical rotation spectrum for nuclei with odd A and spin $\frac{1}{2}$.[6] However, the data[3,5,7] for the low energy γ-transitions $\sim$ 8 and 21 kev, which are difficult to study, were not sufficiently reliable. The purpose of the present work is to investigate these transitions.

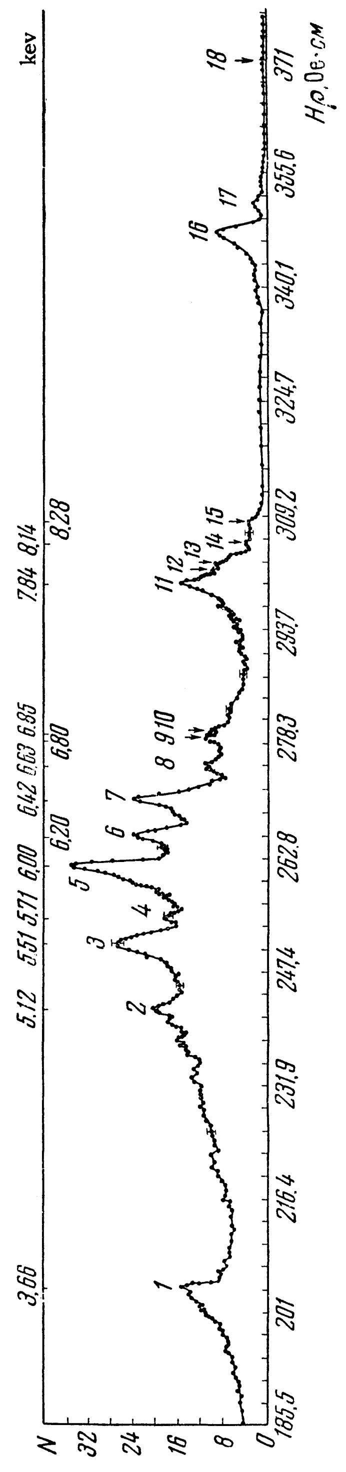
The radioactive source used in our work was Yb^{169}, which decays by K-capture with half-life $T_{\frac{1}{2}} = 30.6$ days,[8] and which was produced by slow neutron irradiation of a natural mixture of isotopes of ytterbium in the Physics-Engineering Reactor.[9] The study of the electron spectrum of Yb^{169} was done with a magnetic beta-spectrometer having $\pi\sqrt{2}$ focusing ($r_0 = 27$ cm). Thin celluloid film was used for the window of the Geiger counter to transmit electrons with energy $\sim$ 2 kev, and for the source backing. The 2 × 25 mm source was prepared by evaporation from an aqueous solution of ytterbium chloride. Aquadag was used to make it a conductor. The spectrometer was calibrated using the conversion lines of Np^{237}. The electron spectrum was studied over the energy interval from 3 to 70 kev. The figure shows the low energy region from 3 to 13 kev. No electron lines were found which did not belong to Tm^{169}. The half width of the conversion lines was $\sim 0.7\%$.

Because of insufficient resolution the Auger spectrum produces a continuous background of electrons. The Auger peaks 2, 3, 4, 8 were detected in the 3 — 8 kev range. From Table I, we see that the theoretical and experimental energy values coincide for these Auger lines.

Let us consider the relative intensity of some of the Auger transitions. We know that in the decay of Yb^{169} a considerable fraction of the γ-transitions are magnetic and electric dipole transitions, which are more strongly converted in the L_I subshell than in the other L subshells. We should therefore expect that the $L_I \rightarrow M_I M_I$ will be the most intense of all the Auger transitions of this series. If we look at the figure, we see that the Auger transition $L_I \rightarrow M_I M_I$ (peak 3) is actually considerably more intense than the next transition $L_I - M_I M_{II}$ (peak 4) and the transitions $L_{II} \rightarrow M_I M_{II}$; $L_{III} \rightarrow M_{II} M_{IV}$ (peak 2) etc. Consequently we should suppose that the Auger lines which coincide with the conversion lines (5, 6, 7 etc.) have still lower intensity and do not produce any essential distortion of the shape of those lines. The interpretation of the Auger lines and conversion electrons is given in Table I.

Conversion of 8.32 kev γ-rays is observed on all the M- and N-subshells. The intensity of the conversion lines (cf. Table I) was computed taking into account the possible contribution from Auger electrons. By comparing the experimental and theoretical values given in Table II for the relative probability of conversion of this γ-ray on the M-subshells (for M1 and E2 transitions), we may conclude that this γ-radiation is a mixture of magnetic dipole and electric quadrupole radiation. Since the absolute conversion coefficient for magnetic dipole radiation is much smaller than for electric quadrupole radiation (from a rough estimate, $\alpha_2/\beta_1 \gg 10$), apparently the admixture of E2 amounts to at most a few percent (< 3).

Conversion of the 20.65 kev γ-rays is observed on the L-, M- and N-subshells. The conversion lines L_{III}; M_I; M_{II}; N; O (#19, 20, 21, 22, 23 in



Low energy region of the Yb^{169} electron spectrum. The ordinates give the number of counts, divided by 64. The numbers on the curve mark the electron lines, whose characteristics are given in Table I.

TABLE I

Number of electron line	Energy of conversion electrons, kev	Shell in which conversion occurs	Energy of γ-transition kev	Intensity in arbitrary units	Multipolarity
1	3,72	K	63,12±0,05		
5	6,00	M_{I}	8,31	12,00±1,0	
6	6,20	M_{II}	8,29	5,00±0,50	
7	6,42	M_{III}	8,31	5,80±0,75	
9	6,80	M_{IV}	8,32	0,66±0,20	
10	6,85	M_{V}	8,32	0,54±0,15	
11	7,84	N_{I}	8,31	5,58±0,40	
12	7,95	N_{II}	8,33	2,96±0.23	
13	7,99	N_{III}	8.33		
14	8,14	$N_{IV,\,V}$	8,32	0,51±0,13	
15	8,29	O	8,34	0.35±0,12	
		Average	8.32±0,05		$M1+E2(<3\%)$
16	10.51	L_{I}	20,65	3,56±0.18	
17	10,00	L_{II}	20,63	0,50±0.11	
18	11,94	L_{III}	20.60	0,11±0.03	
19	18,35	M_{I}	20,66	0,29±0.06	
20	18.53	M_{II}	20,62	0.07±0.03	
21	18,86	M_{III-V}	20.65		
22	20,19	N_{I-V}	20,66	0.07±0.03	
23*	20.63	O	20,66	0.007±0,004	
		Average	20,65±0,07		$M1$

Auger lines

Number of line	Transition	Electron energy, kev	
		theor.	exptl.
2	$L_{II}\to M_{I}M_{II};\ L_{III}\to M_{II}M_{IV,\,V}$	5,0—5,2	5,12
3	$L_{I}\to M_{I}M_{I}$	5,51	5,51
4	$L_{I}\to M_{I}M_{II}$	5,72	5,72
8	$L_{I}\to M_{I}M_{V};\ L_{I}\to M_{IV}M_{V}$	6,56—6,71	6,63

*Electron lines 19-23 are not shown on the figure.

TABLE II

γ-transition kev	Subshells	Relative conversion probability		
		Experimental data	Theoretical value*	
			M1	E2
8,32	$M_{I}:M_{II}:M_{III}:M_{IV,V}$	(1,00±0,13) : (0,42±0.13) : : (0,48±0,13) : (0,10±0,03)	1 : 0,11 : 0,004 : : 0,009	1 : 250 : 500 : 35
20,65	$L_{I}:L_{II}:L_{III}$	(1,00±0,05) : (0.14±0.03) : : (0.03 ± 0.01)	1 : 0.10 : 0.03	1 : 250 : 250
	$M_{I}:M_{II-V}$	(1.0 ± 0,2) : (0,2 ± 0,1)	1 : 0,12	1 : 1000

*Approximate values from Church and Monahan.[12]

Table I), which are not shown on the figure, were detected using a more intense source. Comparison of experimental and theoretical values for the relative probabilities for conversion on L- and M-subshells (for M1 and E2; cf. Table II), shows that the 20.65 kev γ-transition is a pure M1 (with no E2 admixture).

For the 63.12 kev γ-transition, only the K-conversion line #1 is shown on the figure. The intensity of the line is greatly reduced because of absorption in the source and in the film over the window of the counter. We did not study the conversion of these γ-rays in other shells. Except for those enumerated (8.32, 20.65 and 63.12 kev), no other γ-rays were detected in the energy interval 3 — 70 kev.

During the time of this investigation we learned of the work of Hatch et al.,[10] who also studied the low energy γ-transitions in Tm^{169}. These authors state that the 8.42 and 20.75 kev γ-transitions are magnetic dipole (M1),* whereas according to our data the first transition is M1 + E2 (< 3%), while the second is M1. In the same paper it is shown that the rotational band (for $K = \frac{1}{2}$) has levels with spins of $\frac{1}{2}^+$, $\frac{3}{2}^+$, $\frac{5}{2}^+$, and $\frac{7}{2}^+$, while the level with spin $\frac{9}{2}^+$ is absent. Our measurements are in accord with these data.

Computations by Zaretskii based on the coupling scheme treated in Reference 13 show that the 8.32 and 20.65 kev γ-transitions in Tm^{169} should be mainly magnetic dipole, with a possible small admixture of E2 (a few percent). As one can see, the experimental data are not in contradiction with this result.

In conclusion, we express our gratitude to D. V. Timoshuk for much valuable advice.

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DENSITY OF He^3 — He^4 *SOLUTIONS*

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The density of He^3 — He^4 solutions at saturated-vapor pressure was determined as a function of the temperature at He^3 concentrations of 10, 20.1, 30.3, 41.2, 49.9, 68.5 and 85.4%. The break in the $\rho(T)$ curve affords an estimate of the λ point temperatures for concentrations of 10, 20.1, 30.3, and 41.2%.

THE usual pycnometer method was used to determine the density of He^3 — He^4 solutions. The pycnometer (see Fig. 1) comprised a small glass bulb 1, which narrows down into a capillary 2 of volume 6.5×10^{-3} cm^3/mm and length 29 mm. A platimun "cup" 3 is fused into the lower half of the bulb. This cup is needed to accelerate the equilibrium between the solution in the bulb and the helium in the bath. The cup has a volume of 0.44 cm^3. Marker 4, etched on the capillary, was used as the reference.

Capillary 2 was checked with mercury for absence of taper, after which the volume of the pyc-

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*A supplementary communication[11] states that the 8.42 kev γ-transition has multipolarity M1 + E2.