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Abstract

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DECAY OF THE TWO-HOUR ISOTOPE Lu^{168}

In the lutetium fraction of the products of irradiation of tantalum with protons of energy 660 MeV, conversion lines were detected whose intensity decreased with a period of about 2 h. In Ref. ([1]), using a magnetic-lens spectrometer, a line with electron energy 77.5 keV and decay period $T = 100 \pm 20$ min was found. The corresponding region of the spectrum was studied again on a double-focusing spectrometer in Ref. ([2]). In that work the existence of a line with half-life $T = 2.0 \pm 0.3$ h was confirmed and its energy was refined: $E_e = 78.7 \pm 0.1$ keV.

Our aim was to investigate the decay of 2-hour lutetium, to which the line that had been found belongs. For the investigations a double-focusing β-spectrometer with angle $\pi\sqrt{2}$ and resolution 0.15% was used. The magnetic field was measured directly by the proton-resonance method. The sensor was placed at the center of the instrument, where a homogeneous field had been specially created. Since the topography of the spectrometer magnetic field depends on the magnitude of the field, we carried out a calibration using lines whose energies are known with high accuracy. The isotopes Th $(B + C + C' + C'')$, Yb^{169}, Cs^{137}, and others were used. Among the lutetium isotopes present in our sources there was Lu^{170}, with the well-known transition $h\nu = 84.19$ keV. The L-conversion lines of this transition were measured immediately before and after the measurements of the lines of 2-hour lutetium. Registration was carried out with two Geiger-Müller counters connected in a coincidence circuit. The intrinsic coincidence background was 1 count/min.

Table 1

Conversion lines of 2-hour lutetium

$H\rho$, gauss · cm	E_e, keV	Identification	Transition energy, keV
974.1	77.54	L_{II}	87.52
981.4	78.64	L_{III}	87.54 ± 0.04*
1036.5	87.03	N_1	87.52

* Possible systematic error has been taken into account.

Measurements were made with two sources. Three conversion lines were detected. We identified them as L_{II}-, L_{III}-, and N-conversion lines (see Fig. 1). The intensity of the first two decreased in the first hours with a period of (2.15 ± 0.20) h. The energies of the lines are given in Table 1.

Figure 1 shows the L_{I+II}- and L_{III}-conversion lines. These lines were observed against the spectral background of longer-lived lutetium isotopes. At a short distance from the 2-hour lines there are lines belonging to the decay of Lu^{167} and Yb^{167}, which are in equilibrium and decay with a period of 56 min. These lines made observation of the K- and M-lines of the 2-hour transition difficult. The N-line is also in the immediate vicinity of lines of other isotopes.

By comparing the energy differences of the $L_{III} - L_{II}$- and $N - L_{III}$-lines with x-ray data, it was established that the transition occurs in the ytterbium nucleus.

Table 2 gives a comparison of the X-ray data with experiment. The ratio of the intensities of the L_{II}- and L_{III}-lines turned out, to an accuracy of 15%, to be equal to unity. The L_I line did not appear in the spectrum, and it may be concluded that its intensity does not exceed 25% of the intensity of the L_{III} line. Comparing these results with the ratio of the theoretical conversion coefficients on the L_I, L_{II}, and L_{III} subshells of the ytterbium nucleus for an energy of 87.54 keV, one can draw a conclusion about the multipolarity of the transition.

Only transitions of type $E2$ and $E3$ have a ratio of the intensities of the L_I, L_{II}, and L_{III} lines close to the experimental one. It is most probable that the multipolarity of the transition is $E2$, since, first, the experimental ratio agrees better with the theoretical one for an $E2$ transition and, second, in no ytterbium nucleus has a transition of type $E3$ been observed so far. Transitions of type $E2$ with an energy of about 80 keV are usually observed in the de-excitation of the first rotational level of even-even ytterbium nuclei. Thus, the L-lines of the 84.19 keV $E2$ transition in Yb^{170} in the decay of Lu^{170} give exactly the same spectrum as the L-lines of the 2-hour lutetium.

Table 2

Comparison of experimental data on the energy differences $L_{III} - L_{II}$ and $N - L_{III}$ with X-ray data

Nucleus	$L_{III} - L_{II}$, keV (X-ray)	$L_{III} - L_{II}$, keV (exper.)	$N - L_{III}$, keV (X-ray)	$N - L_{III}$, keV (exper.)
Tu	0.96	1.10 ± 0.07	8.19	8.39 ± 0.15
Yb	1.03	1.10 ± 0.07	8.46	8.39 ± 0.15
Lu	1.10	1.10 ± 0.07	8.75	8.39 ± 0.15

Regarding the mass number of the new lutetium isotope, one may put forward an assumption based on the available data in the literature on already known Lu isotopes, as well as on the fact that in the reaction Ta + p (660 MeV) nuclei with a greater neutron deficiency are formed predominantly.

Known neutron-deficient lutetium isotopes with odd A are: Lu^{173}, Lu^{171}, Lu^{169}, Lu^{167}. Their decay has been studied, and in their spectra no transition with an energy of 87.54 keV is observed. Lighter isotopes should have a half-life considerably shorter than 1 hour, since the decay energy for them is very large. Isotopes with even A are also known: Lu^{172} and Lu^{170}. In their decay, levels of daughter ytterbium isotopes are excited whose energy is well measured: $E_1^+(Yb^{172}) = 78.7$ keV, $E_1^+(Yb^{170}) = 84.2$ keV. If the isotope under consideration has even A and $E_1^+ = 87.54$ keV, then one may expect that $A < 170$ and, probably, is equal to 168.

Figure 1. L_{I+II} and L_{III} conversion lines of the transition with energy 87.5 keV (background subtracted) 1 hour (a) and 4.3 hours (b) after separation of the fraction. The line shown at left decayed with a period of about 1 hour.

Fig. 1. L_{I+II} and L_{III} conversion lines of the transition with energy 87.5 keV (background subtracted) after 1 hour (a) and after 4.3 hours (b) following separation of the fraction. The line shown at left decayed with a period of about 1 hour.

Recently two papers appeared (^{3}), in which it was reported that, upon irradiation of ^{168}Yb enriched to 30% with protons of energy 6 MeV, the isotope Lu^{168} was obtained with a half-life $T_{1/2} = 7.1$ min. With the aid of a scintillation γ-spectrometer

γ rays with energies 87 ± 1, 900, 987, 1410, 1800, and 2130 keV and the x radiation of ytterbium were detected. Our value for the transition energy agrees well with the energy of the softest γ rays detected by Wilson and Pool.

The energy of the first excited level of even-even deformed nuclei with a given Z depends on the number of neutrons in them. Figure 2 shows

Fig. 2. Position of the first excited levels of even-even deformed nuclei as a function of the number of neutrons N

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this dependence for a series of isotopes. It is seen that the excitation energy of Yb^{168} agrees with the general course of the curve for ytterbium isotopes.

$_{71}Lu^{168}$ is an odd-odd deformed nucleus. In the ground states of such nuclei the spin is usually equal to the sum or difference of Ω_p and Ω_n (the projection of the angular momentum of the odd nucleon on the symmetry axis of the nucleus). Odd-even nuclei Lu^{171}, Lu^{169}, and Lu^{167} have $\Omega_p = 9/2-$. The odd 97th neutron, according to the Nilsson scheme, is in the 5/2 state, and this is confirmed experimentally. Therefore one may expect that the ground state of Lu^{168} is of type 7^- or 2^- $(9/2 \pm 5/2)$.

According to Gallagher and Moszkowski, one should expect that the ground state will be of type (7^-) (the states $9/2 - [514]$ and $5/2 + [642]$; the total angular momenta combine so that the spin angular momenta of the odd proton and neutron are parallel). It may be supposed that the states of Lu^{168} with half-lives of 7.1 min and 2.15 h are two isomeric states of type 7^- and 2^-. The state with a half-life of 7.1 min, observed by Wilson and Pool, is probably the first of these, i.e., a state of type 7^-: at a high spin value of the initial state the high levels are excited more strongly, and Wilson and Pool observed many hard γ lines.

Fig. 3. Decay scheme of Lu^{168}

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Since no positron spectrum of 2-hour lutetium was observed, the decay energy can only be estimated using semiempirical formulas. This energy is equal to 4.6 MeV according to Cameron and 3.8 MeV according to Levy.

Table 3

Comparison of the experimental ratios $L_I : L_{II} : L_{III}$ with theoretical ones for various multipolarities of the γ-transition of 87.54 keV

Multipolarity	$E1$	$E2$	$E3$	$M1$	$M2$	$M3$
$L_I : L_{II} : L_{III}$ theoretical	2.65:0.76:1	0.14:1.03:1	0.023:1.17:1	60:5.7:1	41:0.67:1	0.79:0.13:1
$L_I : L_{II} : L_{III}$ experimental		$(0.25) : (1.02 \pm 0.15) : 1$				

Fig. 3 shows the decay scheme of Lu^{168}, constructed from the data presently available.

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