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ENERGY LEVELS OF ^{101}Ru FED IN THE ELECTRON CAPTURE DECAY OF ^{101m}Rh

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Abstract: Gamma-gamma coincidences and internal conversion electrons observed in the decay of ^{101m}Rh($T_{\frac{1}{2}} = 4.5$ d) allow the establishment of transitions with energies (in keV): 127.08±0.08 (0.4±0.1), 182±2 (0.4±0.1), 232±7 (0.4±0.1), 234±5 (0.7±0.3), 306.79±0.07 (100), 359±7 ($\ll$ 0.4) and 541±5 (6±1). A level sequence of energies, 0, 127, 307, 359 and 541 keV with characteristics $\frac{5}{2}^+$, $\frac{3}{2}^+$, $\frac{7}{2}^+$, $(\frac{3}{2}, \frac{5}{2})$ and $(\frac{7}{2}, \frac{9}{2})^-$, respectively, is proposed. Two electron capture branches from the $(\frac{9}{2}^+)$ isomeric state of ^{101}Rh to the 307 keV and 541 keV levels, respectively, are consistent with the scheme.

The isomeric transition of energy 157.26±0.03 keV has a K/L/M ratio of 100/31/8.

In the decay of ^{101}Rh($\approx$ 5 y) two transitions of energies 127.09±0.09 and 197.9±0.2 were detected.

E | RADIOACTIVITY ^{101}Rh, ^{101m}Rh [from ^{104}Pd(d, dn)] measured E_γ, $I_{\gamma, x, ce}$, $\gamma\gamma$-coin, cc. ^{101}Ru deduced levels, J, π, log ft. Natural target.

1. Radioactive Source

Natural palladium was bombarded with 15 μAh of 28 MeV deuterons at the Buenos Aires synchrocyclotron. The palladium target and the ruthenium activity were retained on a strong anion resin. Rhodium activities were repeatedly coprecipitated on $Fe(OH)_3$ in the presence of silver carrier. The iron was extracted with ethyl ether and a final purification through a small anion resin column was performed. Finally, the Rh carrier-free activity was electroplated in dilute sulphuric solution on 3.6 mg/cm^2 nickel-copper foils for the gamma-ray sources and on 0.22 mg/cm^2 nickel foils for the conversion electron sources. The preparation of the rhodium sources is further described elsewhere [1]).

2. Instrumentation

For X- and single γ-ray measurements a thin entrance window 7.6 cm×7.6 cm NaI(Tl) crystal was used, associated with a multichannel analyser.

Gamma-gamma coincidences were performed with a conventional set-up. Two NaI(Tl) crystals of 4.4 cm diam by 5.1 cm height were coupled to a fast-slow coincidence circuit, set at a resolution time $2\tau = 50$ nsec and connected to a multichannel analyser. The axes of the detectors were at 90° to each other and the radio-

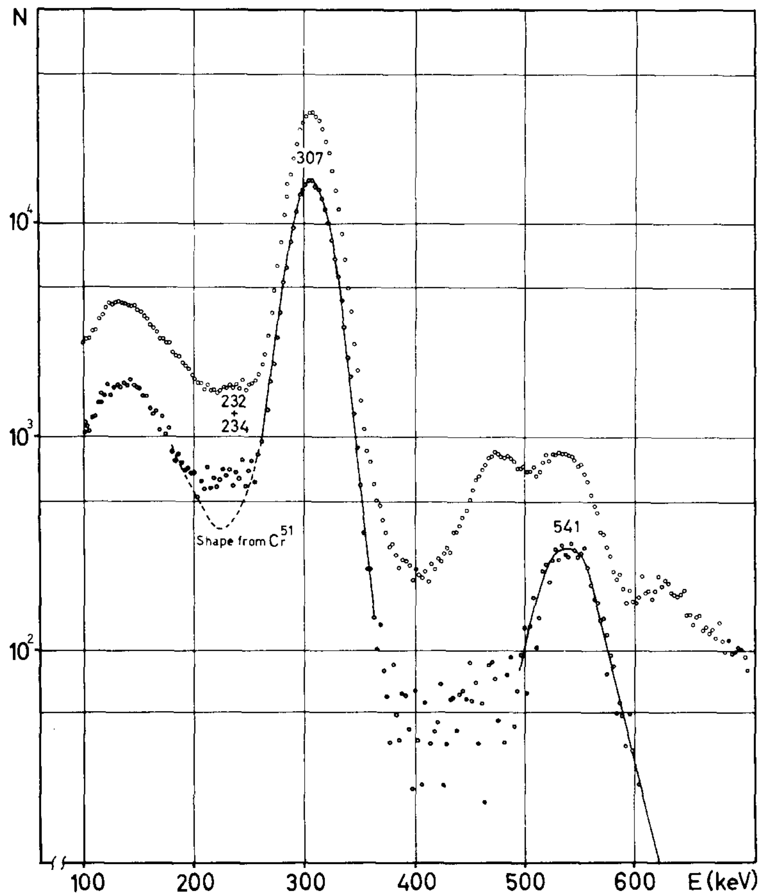

Fig. 1. Single spectra. Upper, spectra of ^{101m}Rh, ^{99}Rh, ^{102}Rh and ^{101}Rh together. Lower, ^{101m}Rh spectrum.

TABLE 1

Gamma-ray energies and relative intensities in ^{101m}Rh decay

E (keV)	Relative intensities [a])						
	Single spectrum	Spectra in coincidence with gamma rays of energies (keV)					
		127	182	232+234	307	359	541
127			yes	0.24±0.10			
182		yes		0.27±0.11		yes	
232+234	1.0±0.3	yes	yes		0.65±0.25		
307	99			0.65±0.25			
359			?				
541	6±1						

[a]) The intensities are normalized to the value 100 for the total intensity of the 307 keV transition.

active source was placed at 6 cm distance from both crystals. Between the detectors was placed a 3 cm thick lead shield. The efficiency of the coincidence system for energies above 100 keV was the same as in the single gamma measurements.

In addition, a double focussing iron yoke magnetic spectrometer was used to scan several energy regions at a resolution setting of 0.23 % in momentum.

3. Single Gamma Spectrum

Eight days after irradiation ^{101m}Rh (4.5 d), ^{99}Rh (16 d), ^{102}Rh (206 d) and ^{101}Rh ($\approx$ 5 y) were present in the source. In order to obtain the ^{101m}Rh spectrum, differ-

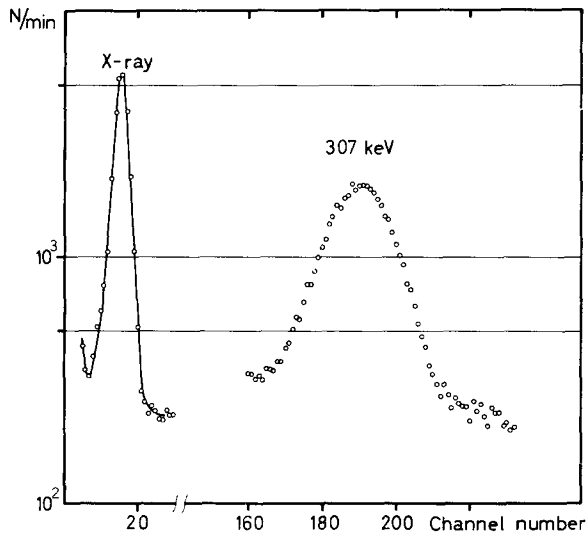

Fig. 2. Single gamma spectrum showing the X-ray and 307 keV gamma-ray peaks.

ences between spectra taken 1–4 d apart were made (fig. 1). The relative intensities of the resulting gamma transitions are shown in column 2 of table 1. These are the already known transitions in ^{101}Ru observed in ^{101m}Rh electron capture decay [2]. The energies given in the tables and figures and in the entire text are those obtained after completion of the measurements and not those resulting from the specific experiment quoted.

Fig. 2 shows the X-ray peak and the 307 keV gamma ray. Their intensities are respectively $(62 \pm 6) \times 10^5$ and $(64 \pm 6) \times 10^5$ counts/min.

The low-energy region (below 100 keV) was analysed with more detail using a NaI(Tl) crystal of 2.5 cm × 2.5 cm. No gamma transition with a half-life of about 4.5 d was observed.

4. Gamma-Gamma Coincidence Spectra

When evaluating the coincidence spectra only the energy region above 100 keV was processed. The obtained results are quoted in table 1 for those peaks having a half-life of about 4.5 d; those arising from coincidences with Compton distributions of longer-lived isotopes could easily be identified. The coincidence spectrum with the (232+234) keV transitions in gate is shown in fig. 3.

Setting a gate of 15 keV width successively at 335, 350 and 365 keV, a peak at 180±5 keV was observed in all coincidence spectra. It faded out for higher energies

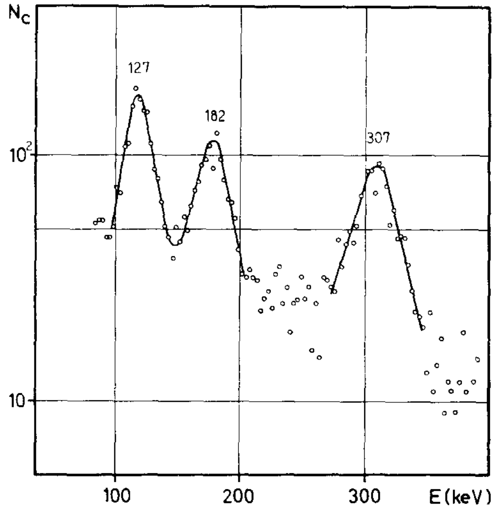

Fig. 3. Coincidence spectrum with the 230 keV region in gate, chance coincidences are subtracted.

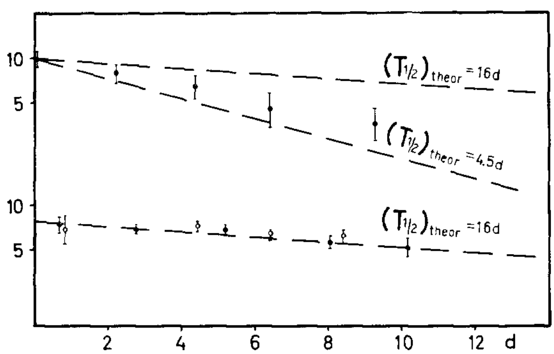

Fig. 4. Decay of the 180 keV peak in coincidence with the 335–365 keV region in gate. Upper: gate at 365 keV, lower: gate at 350 keV (●) and at 335 keV (o).

in gate. Fig. 4 shows how this peak decayed for the different positions of the gate. The half-life of very nearly 16 d for the first two settings is attributed to the (349; 175) keV coincidences in ^{99}Rh decay; it is evidently shorter when the gate is at 365 keV. In the latter case, it seems very plausible to attribute the coincidence peak to the combined effect of (349; 175) keV coincidences from ^{99}Rh and the coincidences of a transition of ≈ 365 keV in ^{101}Ru with the 182 keV transition.

Two gamma rays of energies 127 keV and 232 keV appeared clearly in the coincidence spectrum with the gate covering the (180–210) keV region (fig. 5). The intensities and half-lives of these coincidence peaks were very different, since in the 127 keV peak the (198; 127) keV coincidences from ^{101}Rh decay were also present. The intensity in coincidence of the 359 keV transition could not be determined from the present experiments but, undoubtedly, it is weaker than the intensity of the 232 keV transition.

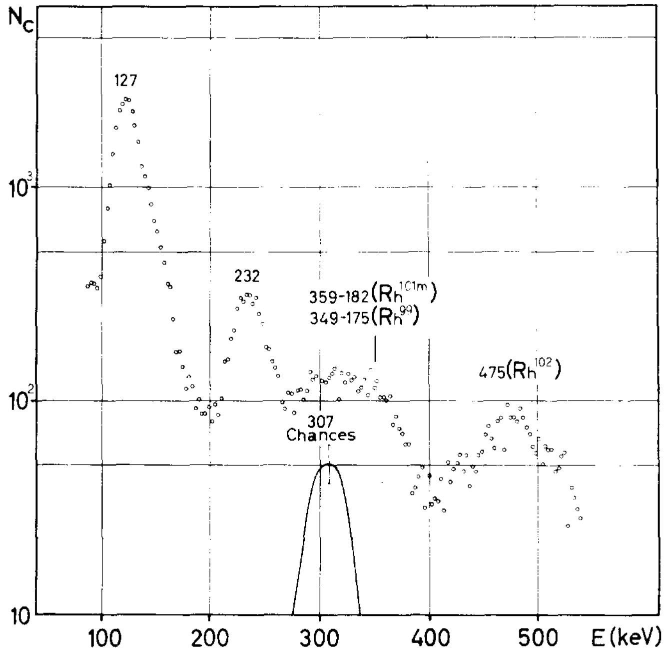

Fig. 5. Coincidence spectrum with the 180–210 keV region in gate.

Within the statistical errors no coincidences with a possible transition of 414 = 182+232 keV have been observed up to 480 keV.

5. Conversion Electron Spectrum

The conversion electron spectra in electron energy regions from (in keV) 98.8 to 126.5; 131.3 to 135.9; 150.8 to 162.9; 173.4 to 178.5; 208.0 to 286.3; 298.2 to 307.0 and 514.3 to 522.3 were surveyed a few days after the preparation of the sources (see fig. 6).

5.1. THE ISOMERIC TRANSITION

The energy of the M4 isomeric transition, obtained from its K and L conversion lines, is 157.26±0.03 keV. The intensity of the K-conversion line is 3.4±0.4 times

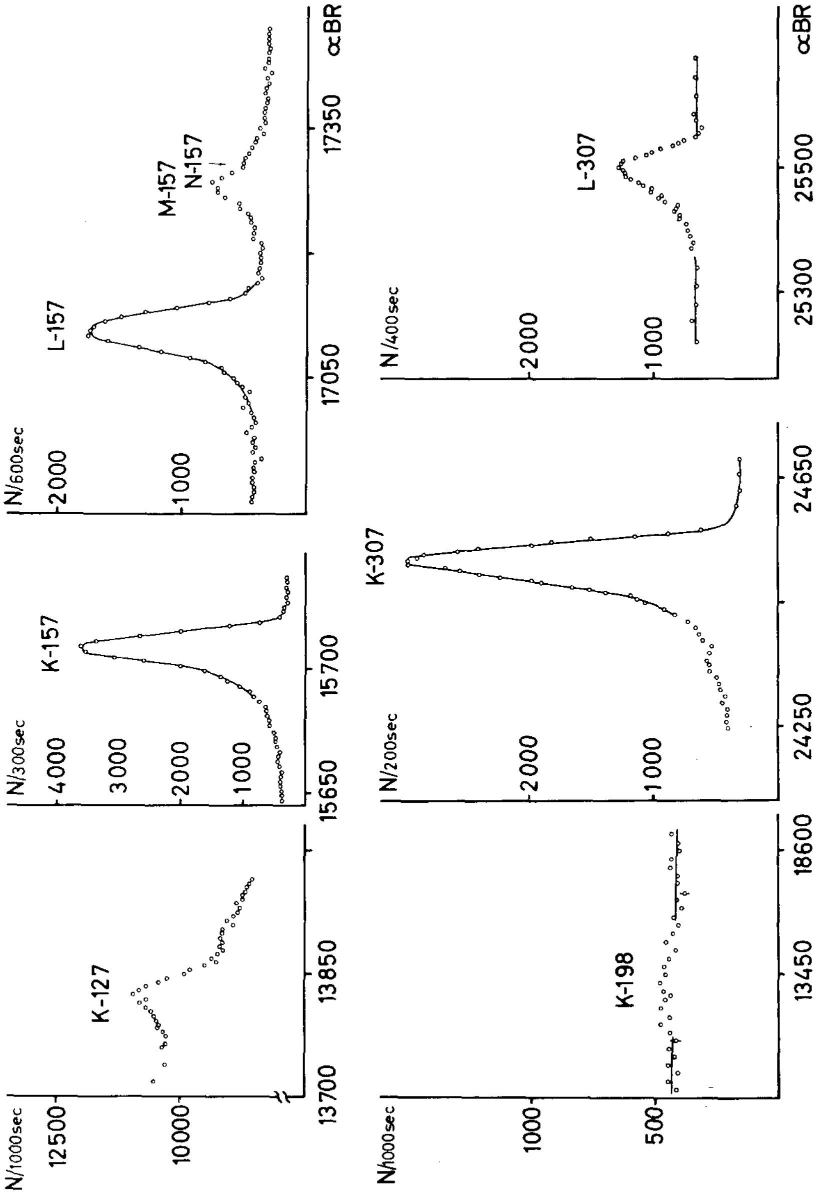

Fig. 6. Conversion electron spectrum.

that of the 307 keV K-conversion line and its K/L/M ratio 100/31/8, which confirms previously reported values [3]). From this information the intensity of the isomeric transition related to the electron capture decays was calculated as 6.5 ± 1.0 %.

5.2. INTERNAL CONVERSION LINES OF TRANSITIONS IN ^{101}Ru

The observed conversion lines are reported in table 2 with the intensities normalized in such a way as necessary to obtain for the 307 keV transition the theoretical M1 conversion coefficient (subsect. 5.3).

The conversion lines of the 182 keV transition have not been distinctly observed; its K-line might be covered by the intense M-N-lines of the isomeric transition and its L-line by the K-line of the 197.9 ± 0.2 keV transition from ^{101}Rh decay.

Peaks which, if assumed to be K-conversion peaks, correspond to transitions of 234.0 ± 0.2 and 539.5 ± 1.5 keV were detected with intensities of 0.008 ± 0.002 and 0.005 ± 0.003, respectively, but their half-lives could not be determined; thus the energy tabulated for the 541 keV transition is the one obtained from the single gamma spectrum. The error stated in table 2 for the energy of the 234 keV transition results from the (541–307) keV difference, and the upper limit for the intensity of the K-conversion lines of the 232 and 234 keV transitions together has been fixed at 0.01.

5.3. THE K-CONVERSION COEFFICIENT OF THE 307 keV TRANSITION

This conversion coefficient was measured against that of the 662 keV transition in ^{137}Cs decay. The result $\alpha_K = 0.012 \pm 0.003$, shows that the 307 keV transition is predominantly M1. This is confirmed by the fact the measured K/L ratio is 8.6 ± 0.6.

5.4. THE ENERGY OF THE FIRST EXCITED STATE OF ^{101}Ru

In order to determine the energy of this level, several months after irradiation the electron spectrum was scanned in the corresponding energy region. The value 127.09 ± 0.09 keV was obtained.

6. Conclusions

The energy levels of ^{101}Ru fed in the decay of ^{101m}Rh according to the present measurements are displayed as fig. 7, where the intensities are normalized to 100 electron capture decays. All transitions stated in table 2 are included.

6.1. THE CONVERSION COEFFICIENTS AND MULTIPOLARITIES

Due to the excellent energy agreement it is assumed that the 127.08 ± 0.08 keV transition (subsect. 5.2) arises at the 127.09 ± 0.09 keV first excited level fed in the ^{101}Rh decay (subsect. 5.4). Then, in order to explain the results obtained from the coincidence measurements with the (232+234) and 359 keV peaks, it is necessary to establish a new level at 359 ± 7 keV.

The conversion coefficients evaluated from the experimental data are quoted in column 4 of table 2 and in column 6, the corresponding multipolarities as deduced from fig. 8 are given.

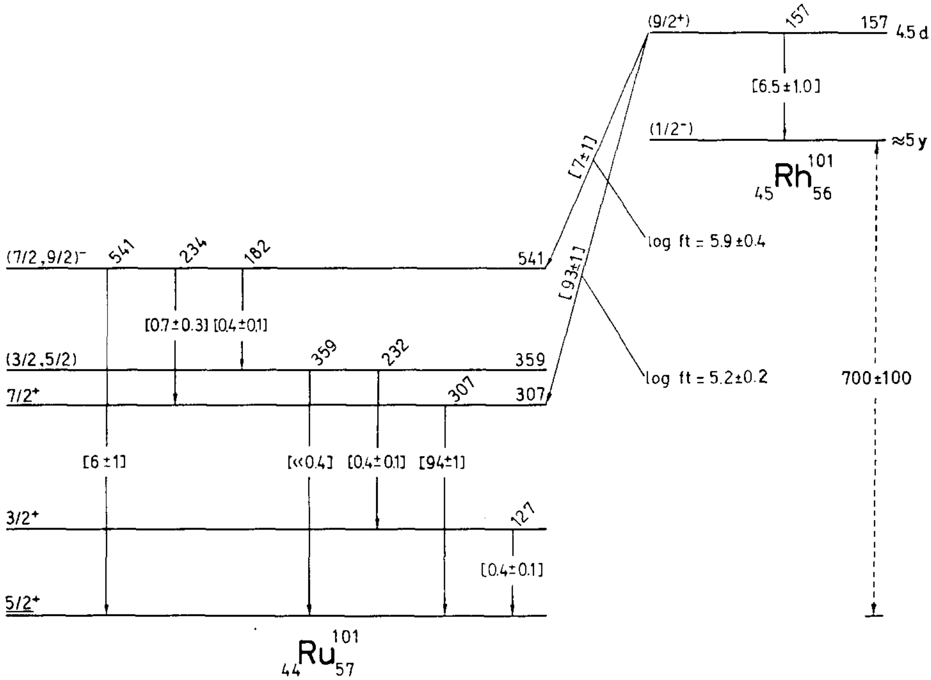

Fig. 7. Energy levels of ^{101}Ru fed in the electron capture decay of ^{101m}Rh. The log *ft* values have been calculated using a *Q*-value from systematics. The intensity of the transitions, including the isomeric transition, are given in brackets for 100 electron capture decays.

TABLE 2

Properties of transitions in ^{101}Ru from ^{101m}Rh electron capture decay

E_γ (keV)	I_γ	I_K	α_K	I_{total}	Multipolarities [b]
127.08±0.08	0.24±0.10	0.09±0.01 [a]	(3.7±1.6)(−1)	0.4±0.1	M1+E2
182 ±2	0.27±0.11			0.4±0.1	
232 ±7	0.4 ±0.1	<0.01 (232 and 234)	<3 (−2)	0.4±0.1	(E1, M1)
234 ±5	0.65±0.25		<2.5 (−2)	0.7±0.3	E1
306.79±0.07	99	1.36	1.37 (−2)	100	<u>M1</u>
359 ±7	≪0.4			≪0.4	
541 ±5	6 ±1			6 ±1	

[a]) The contribution from ^{101}Rh decay has been deduced measuring the K-line of the 198 keV transition and using the known ratio of the K-lines observed in this decay [2]).

[b]) The same multipolarities are obtained assuming that the 307 keV transition is as much as 30 % E2. For the sake of simplicity only the normalization to the multipolarity M1 is shown.

6.2. THE CHARACTER OF THE LEVELS

The conversion coefficients measured for the 127 and 307 keV transitions are consistent with the characters assigned in ref. [2]) to the first and second excited state in ^{101}Ru from other types of experimental evidence.

The E1 multipolarity obtained for the 234 keV transition, leads to the characteristics $(\frac{5}{2}, \frac{7}{2}$ and $\frac{9}{2})^-$ for the 541 keV level. As this level is fed from the $(\frac{9}{2}^+)$ ground state of ^{101}Tc with $\log ft = 5.5$ (see ref. [2])), the spin $\frac{5}{2}$ is excluded.

The K-conversion coefficient of the 232 keV transition does not determine unambiguously its multipolarity. The spin of the 359 keV level may be $\frac{1}{2}$, $\frac{3}{2}$ or $\frac{5}{2}$, but

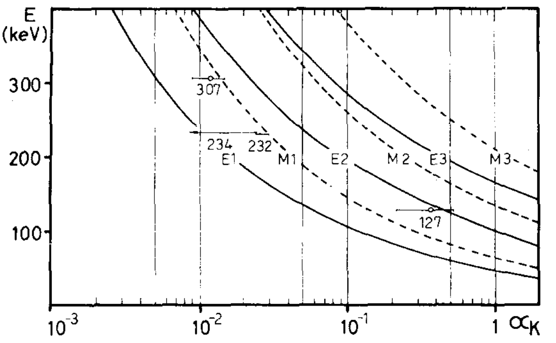

Fig. 8. Theoretical and experimental values of K-conversion coefficients for $Z = 44$. The value for the 307 keV transition was obtained against that of the 662 keV transition in ^{137}Cs decay; the others assuming the 307 keV transition as pure M1 and normalizing to its theoretical K-conversion coefficient.

there is no indication for its parity. Although the L-conversion line of the 182 keV transition could not be observed, the upper limit $\alpha_L \leqq 0.12$ can be established and it indicates $\Delta J \leqq 2$, so that spin $\frac{1}{2}$ is excluded.

6.3. THE ELECTRON CAPTURE FEEDINGS

The nuclear shell model predicts that the lowest energy levels for the 45th proton (Rh) is $\frac{1}{2}^-$ or $\frac{9}{2}^+$ and this is confirmed by experimental evidence in this Z-region. The assignment $(\frac{9}{2}^+)$ to the isomeric state is imposed both by the analogy with the ^{101}Tc ground state decay and the previously stated fact that the X-ray intensity is not larger than the 307 keV transition intensity.

From the previous considerations two electron capture feedings from the ^{101m}Rh state to the 541 keV and to the 307 keV energy levels of ^{101}Ru are established: a $(\frac{9}{2}^+) \rightarrow (\frac{7}{2}, \frac{9}{2})^-(\Delta J = 0, 1$, yes) first forbidden transition with $\log ft = 5.9 \pm 0.4$ and a $(\frac{9}{2}^+) \rightarrow \frac{7}{2}^+$ ($\Delta J = 1$, no) allowed transition with $\log ft = 5.2 \pm 0.2$, in very good agreement with the systematics [4]).

The characteristics assigned to the 127 and 359 keV levels are consistent with the absence of significant electron capture decay feedings to them.

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