ISOMERIC STATES IN $^{97-100}$Rh ISOTOPES

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Short-living isomeric states in neutron-deficient Rh isotopes were investigated with Ge(Li) detectors and a toroidal iron-free electron spectrometer. Decay schemes were proposed for ^{97m}Rh (44 m), ^{98m}Rh (3.5 m), and ^{110m}Rh (4.7 m). The properties of the isomeric transitions observed in Rh isotopes support the shell model interpretation of the low-lying excited states.

1. Introduction

The five proton configurations in the $g_{9/2}$ subshell close to $p_{1/2}$ give rise to the isomeric states in Rh isotopes. An extensive study of similar Ag isomers was completed by CERN and Princeton groups [1, 2] with the help of isotope separators and several spectroscopic methods. Until 1972 isomeric states were well known only in heavier Rh isotopes with $A \geqslant 101$. In ^{99}Rh the position of the isomeric level was not established, while the existence of short living ^{98m}Rh and ^{97m}Rh was suggested [3, 4].

New information about isomeric and other excited states of neutron-deficient Rh isotopes was obtained from decays of $^{98-101}$Pd [5, 6, 7]. Further studies on the short-living Rh isomers were carried out in measurements of the gamma-ray spectra from enriched ^{96}Ru (94.9%) and natural Ru targets irradiated with the 20–43 MeV alpha-particles in the 220 cm cyclotron at the Research Institute for Physics in Stockholm.

2. Experimental methods

The investigated Rh isomers were produced in two different ways:

a) the target material from the Ru (α, pxn) Rh reaction was used for single gamma-ray spectra measurements, starting from one minute after the conclusion of irradiation, and no chemical treatment was performed,

b) carrier-free sources for conversion electron measurements were prepared after decays of the parent Pd isotopes evaporated in vacuum from Ru targets.

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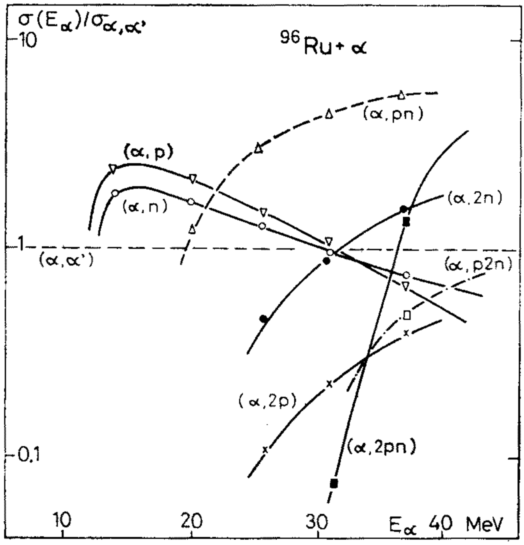


Fig. 1. Relative excitation functions of $^{96}Ru+\alpha$ reactions normalized to $^{96}Ru(\alpha,\alpha')\,^{96}Ru$ reaction

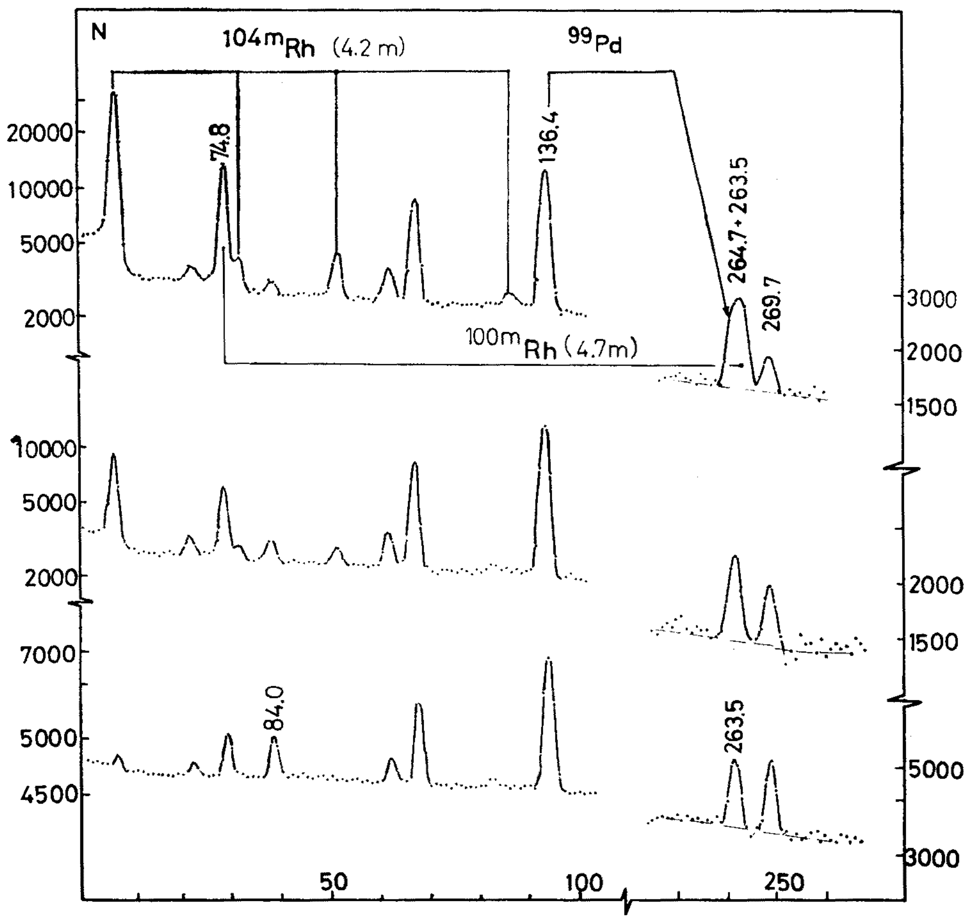
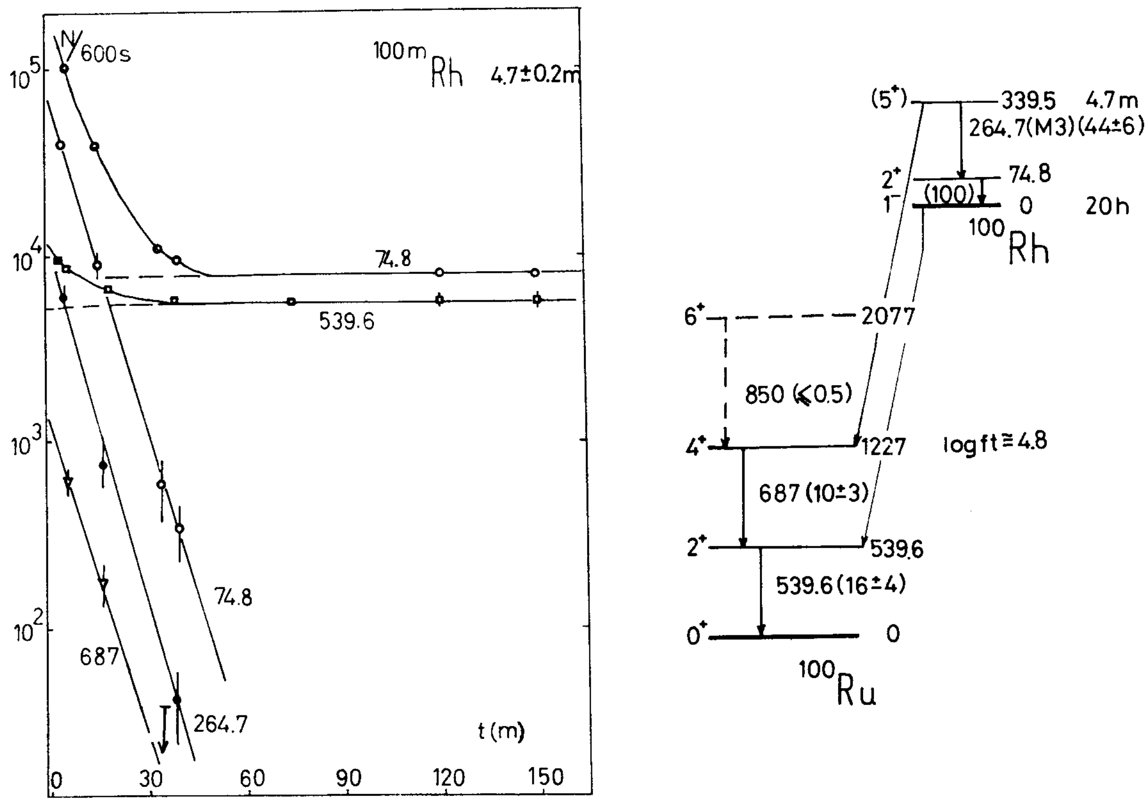


Fig. 2. Three subsequent gamma-ray spectra of short living Rh activities



a b

Fig. 3. (a) Time analysis of decay curves of transitions from ^{100m}Rh. (b) Proposed decay scheme of ^{100m}Rh

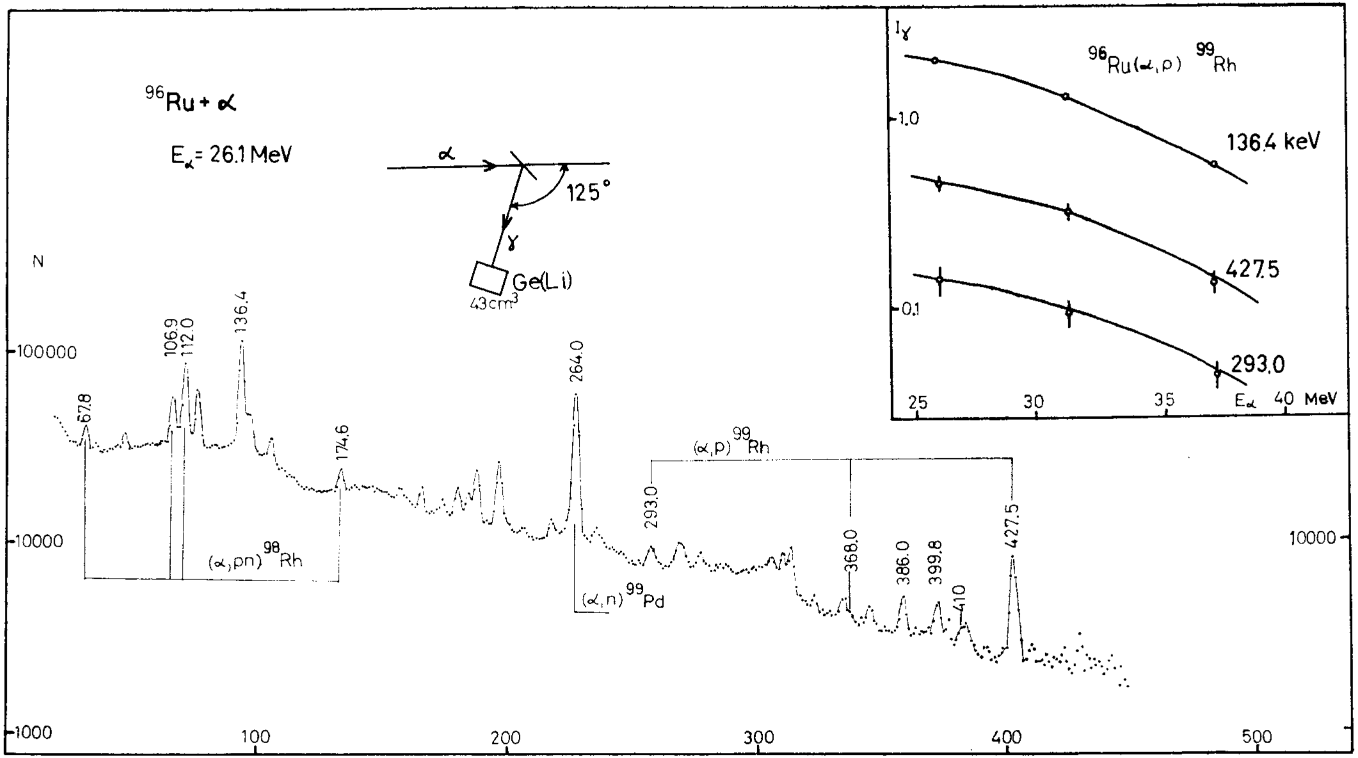


Fig. 4. Low energy fragment of gamma-ray spectrum taken in-beam with transitions in ^{99}Rh

Germanium detectors with a volume of 40 ccm and 2.3 keV resolution for 1332 keV were used in gamma-ray measurements. Spectra were stored in a 4096 channel analyser and transition energies and intensities were deduced with the aid of standard programs on a TRASK computer. The iron-free toroidal spectrometer was used in conversion electron studies in the low energy region [6] to look for possible isomeric transitions.

New experimental data obtained from decays were also supported by the results of the in-beam gamma-ray measurements from ^{96}Ru ($\alpha, pxn\,\gamma$) ^{99,98}Rh reactions [8]; their excitation functions are shown in Fig. 1.

^{100m}Rh (4.7 min)

Excited levels of ^{100}Rh were investigated earlier [9] from ^{100}Pd decay. The isomeric state in ^{100}Rh with $T_{1/2}$ = 4.7 (3) min was identified among short-living activities produced with 43 MeV alpha particles on the natural Ru target. The decay scheme of ^{100m}Rh presented in Fig. 3b is based on the time analysis (Figs 2, 3a) of the well-known transitions in ^{100}Rh (74.8 keV) and in ^{100}Ru (593.6, and 687 keV).

^{99m}Rh (16.1 d)

^{99}Rh excited states were populated in this experiment in the ^{96}Ru ($\alpha, p\gamma$) ^{99}Rh reaction (Fig. 4). A simple comparison of the intensities of the gamma-rays observed in-beam and in ^{99}Pd decays from earlier works [5, 11] (see Table I) confirms the position of the 1/2$^-$ isomeric state at 2.0 (3) keV. This statement is based on the placement of the 293 keV transition between the 429 keV and 136 keV levels proposed earlier in our paper [6], and now supported by observed in beam gamma-ray intensity relations.

TABLE I

Transition energy (keV)	Between the levels of ^{99}Rh	Relative intensities of gamma-rays in decay of ^{99}Pd and in ($\alpha, p\gamma$) reaction		
		from Ref. [6]	Ref. [11]	E_α = 26 MeV
136.4	7/2$^+$ → 9/2$^+$	100	100	100
399.8	5/2$^+$ → 9/2$^+$	6.6(5)		7.3(10)
263.5	5/2$^+$ → 7/2$^+$	28(2)		31(5)
386.0	7/2$^+$ → 5/2$^+$	5.8(4)		6(1)
785.0	7/2$^+$ → 9/2$^+$	5.0(10)		5.0(5)
967.1	(3/2, 5/2)$^+$ → 7/2$^+$		1.3(1)	0.5
293.0	(3/2, 5/2)$^+$ → 5/2$^+$ or 5/2$^-$ → 7/2$^+$	1.8(4)	1.8(3)	7.0(8)
427.5	5/2$^-$ → 1/2$^-$	4.3(4)		21.4(8)

^{98m}Rh (3.5 min)

Careful analysis of the half-lives of observed transitions in a decaying chain ^{98}Pd → → ^{98}Rh → ^{98}Ru (Fig. 5) was based on the results of decay studies of a ^{96}Ru target irradiated with 26–43 MeV alpha particles and compared with earlier results of Bakhru [13] and Antoneva [12]. Fig. 6 shows the 3.5 min activity of the ^{98m}Rh decaying to several levels of ^{98}Ru, well known from the work of Lederer [10]. The exact position of the

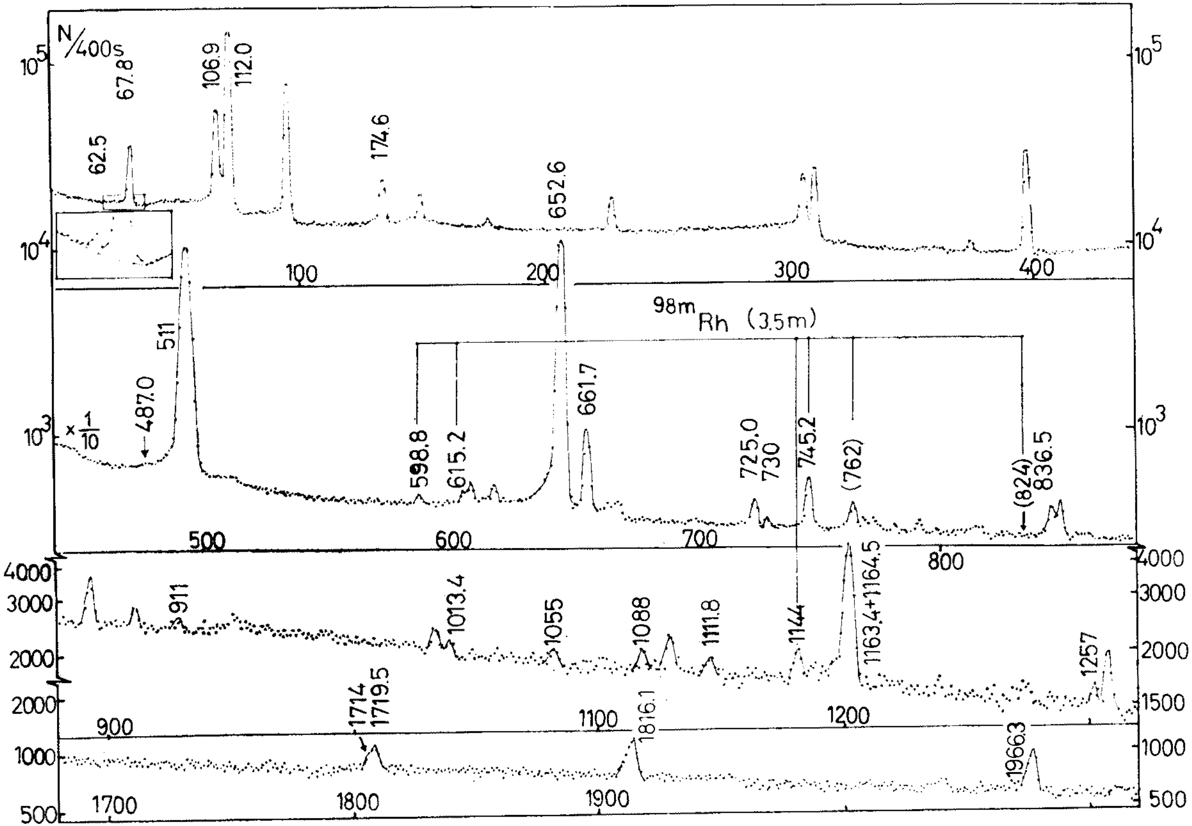


Fig. 5. The gamma-ray spectrum of $^{98}Pd \rightarrow {}^{98}Rh \rightarrow {}^{98}Ru$ decay observed from 1–10 minutes after the conclusion of irradiation

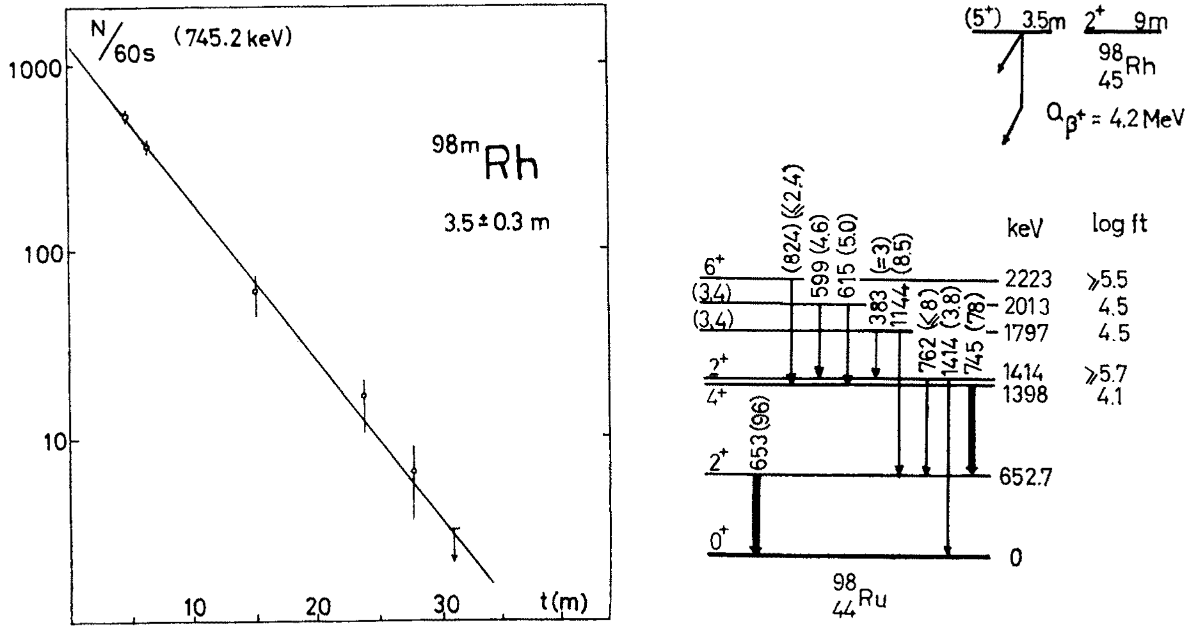


Fig. 6. Decay curve of 745.2 keV transition and ^{98m}Rh decay scheme

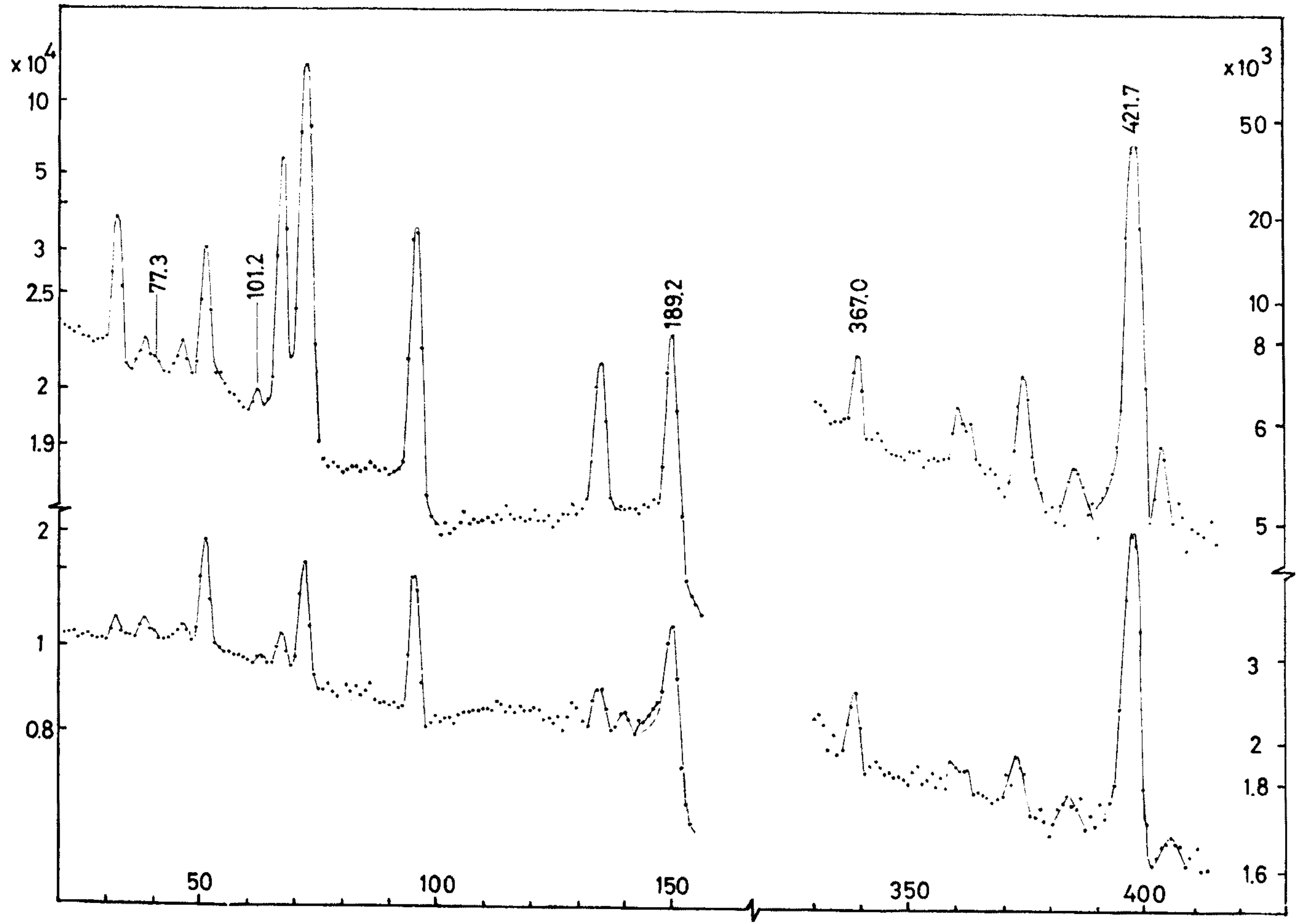


Fig. 7. Details of two subsequent gamma-ray spectra from ^{97}Rh decay

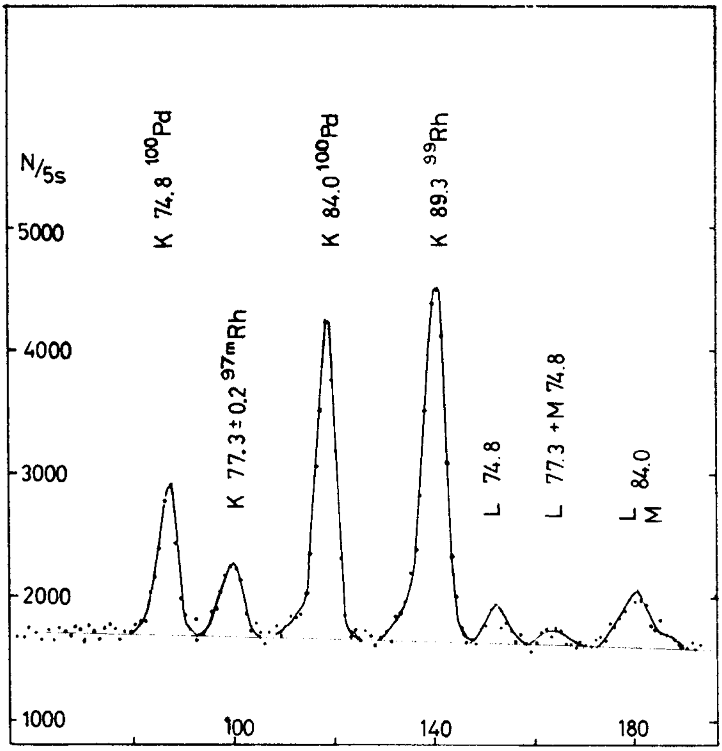


Fig. 8. An electron spectrum with conversion lines of 77.3 keV transition from ^{97m}Rh decay

3.5 min isomeric level in ^{98}Rh cannot be estimated from the present decay experiment. In the recent analysis of the observed ^{96}Ru $(\alpha, pn\gamma)^{98}$Rh reaction [14] the isomeric state is placed at 6.0 (3) keV. The spin of 5^+ is indicated by the allowed β^+ decay to 4^+ and probably to 6^+ states in ^{98}Ru.

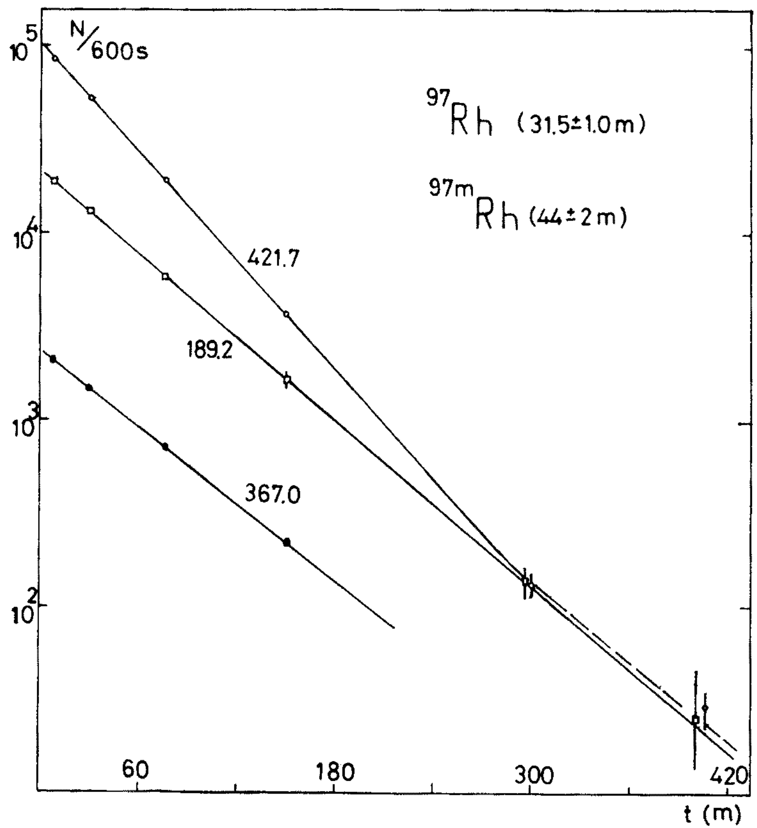
^{97m}Rh (44 min)

Until 1971 several different half-lives of ^{97}Rh were given in the literature [15, 16]. Recently Lopez [17] proposed the existence of an isomer with a spin $9/2^+$ (32 min) and the ground state $1/2^-$ decaying with $T_{1/2} = 44$ min. In our experiment the decay of ^{97}Rh

TABLE II

Retardation factors of isomeric transitions in Rh isotopes deduced from Moszkowski's single proton estimation

Mass number	97	98	99	100	101	102	103	104	105
Isomeric transition, energy (keV), character	(?)	(6.0)	(2.0)	264.7 (M3)	157.3 M4	(?)	40.0 E3	77.5 E3	129.4 E3
Retardation factor				100	1.5		140	80	100



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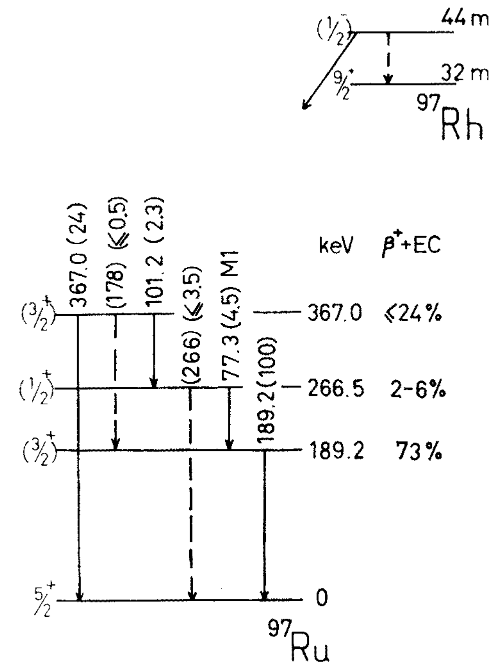

b

Fig. 9. (a) Decay curve of the prominent transitions from ^{97}Rh and ^{97m}Rh decays. (b) ^{97m}Rh decay scheme

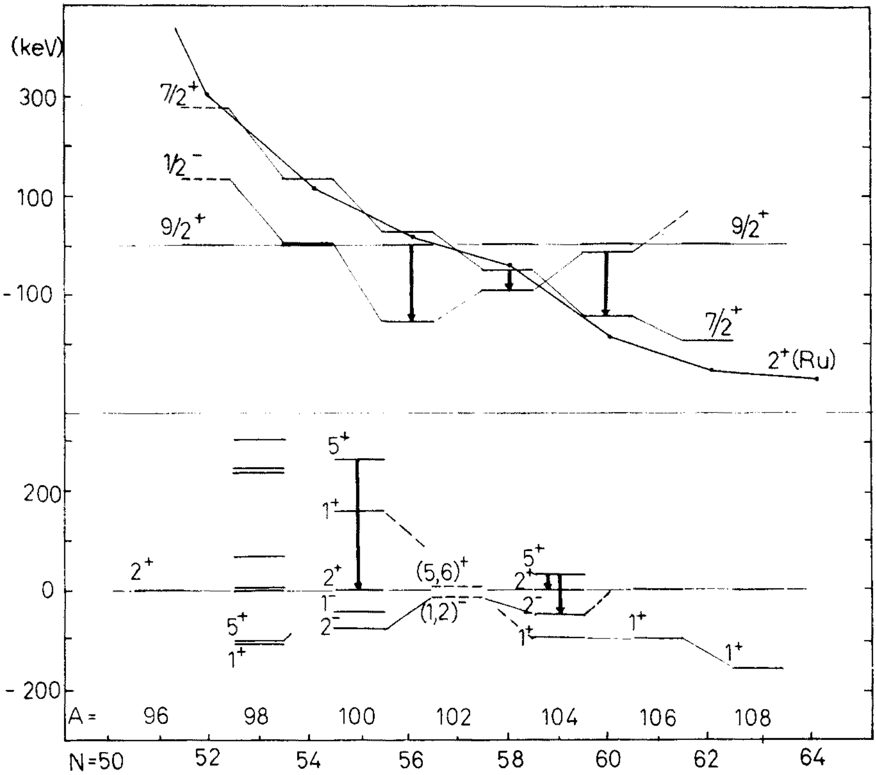

Fig. 10. Diagram of relative positions of low-lying levels compared with $9/2^+$ levels in odd Rh isotopes, with 2^+ levels in odd-odd Rh isotopes, and also with 2^+ levels in even Ru isotones

look longer, and the observed decay curves (Fig. 9a) may suggest a quite different position of the lowest ^{97}Rh levels. The 44 min activity of ^{97m}Rh was also seen in our earlier studies of the electron spectra from the evaporated Pd sources after the decay of the ^{97}Pd (2.7 min) [5] (see Fig. 8).

A tentative level scheme of the low-lying excited states in ^{97}Ru from the ^{97m}Rh decay is presented in Fig. 9b. Such low spin levels are weakly populated in the in-beam studies performed on ^{97}Ru recently by Lederer [10].

3. *Conclusions*

The above presented new data together with others depicted from Tables of Isotopes [18] show a systematic behaviour of the electromagnetic properties of the isomeric states and transitions in Rh isotopes. Fig. 10 illustrates a strong correlation between the relative position of the lowest $9/2^+$, $7/2^+$, $1/2^-$ states in odd Rh isotopes and the 2^+, 0^+ states in neighbour even-even Ru isotones. The odd-odd Rh isotopes also show a similar trend in the relative position of their low-lying levels.

The observed Rh isomeric transition retardation factors are of the order of 100 for E3 and about 1 for M4 transitions in single particle estimation. This fact supports the description of the low-lying excited states in Rh as proton configurations in the $p_{1/2}$ and $g_{9/2}$ subdhells with a sizeable admixture of the $g_{7/2}$ subshell.

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