Some Nuclear States of Rh^{103}†

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The gamma rays emitted in de-excitation of Rh^{103} following beta decay of Ru^{103} have been studied in a Ge(Li) detector and with coincident scintillation counters. Quanta have been detected at energies of 53, 297, 445, 498, 557, and 610 keV with relative intensities of 0.41, 0.31, 0.40, 100, 0.87, and 7.35. The data also indicate the presence of a gamma ray at 65 keV. The K-shell conversion coefficient of the 53-keV gamma ray has been measured to be 1.77 ± 0.03. A disintegration scheme for Ru^{103} has been proposed.

I. INTRODUCTION

THE present paper reports data concerning the energy states of Rh^{103} which lie at excitation energies of 650 keV or less, as determined from a study of the nuclear transitions in Rh^{103} which follow the beta decay of Ru^{103}. The decay of Ru^{103} has been previously studied,[1–13] and the gamma rays associated with the transitions are given in Table I. The energy states of Rh^{103} and the gamma rays related to them have also been observed in primary nuclear reactions. For example, Coulomb excitation of Rh^{103} by alpha particles has yielded gamma ray energies of 295 and 357 keV for γ_4 and γ_6,[14] and 62 ± 2, 298 ± 2, and 360 ± 3 keV for γ_3, γ_4, and γ_6.[15] Coulomb excitation by nitrogen ions gave rise to energy values of 295 and 358 keV for γ_4 and γ_6.[16] By the inelastic scattering of fast neutrons by rhodium,[17] gamma rays at 300 and 365 keV, γ_4 and γ_6, were observed as was a quantum of energy 600 keV, which could not be positively identified as γ_{10}.

Many of the energy states of Rh^{103} are also attained by means of orbital electron capture in Pd^{103}. Gamma rays emitted following decay of Pd^{103} have been reported[8] to have energies of 495, 365, 300, 65, and 40 keV for γ_8, γ_6, γ_4, γ_3, and γ_1, respectively.

In carrying out the measurements discussed in this paper, three different sources were employed over a period of about one year. Two of these were fission fragments, the third formed by slow neutron capture in Ru^{102} (isotropic concentration 99.53%). Numerous gamma rays were observed in addition to those presently reported. By comparisons of the spectra of the three different sources, and by noting the several spectra as a function of time, it was possible to eliminate all other gamma rays except those specifically assigned to Rh^{103} in the text to follow. The unrelated quanta apparently arose from the presence of isotopic and elemental impurities in the various sources.

II. MEASUREMENTS

The spectrum of single counts of the gamma rays of Ru^{103} was obtained, as shown in Fig. 1, employing a Ge(Li) detector (depletion layer thickness 2 mm, encased in iron of thickness 0.05 cm) and a multichannel analyzer. Gamma rays of energies 610, 557, 498, and 297 keV are seen to be present. Though previously detected by using coincidence techniques[8,13] with scintillation detectors, the 557-keV gamma ray was clearly resolved for the first time in a spectrum of single counts. After corrections are made for preabsorption, efficiency of detection as a function of energy, and variation with energy of the full energy peak to total ratio, the relative intensities of the above cited gamma rays, in order of decreasing quantum energy, are 7.35, 0.87, 100, and 0.31.

Though not shown in any figure, the gamma rays of Ru^{103} were also studied in a scintillation counter. The 53-keV gamma ray was clearly observed and used as the "gate" pulse in a coincidence experiment employing an additional scintillation counter. Gamma rays at 445 and 557 keV were found to be coincident with the 53-keV gamma ray as shown in Fig. 2(b). By a comparison with the intensity of the 557-keV gamma ray, the relative intensity of the 445-keV gamma ray was estimated to be 0.40. The results of the measurements of Figs. 1 and 2(b) are summarized in Table II. When the coincidence gate was placed at 65 keV, the 297-keV

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TABLE I. Gamma rays reported in the decay of Ru^{103}. The symbols denote the particle detected for energy determination, γ for unconverted quantum, e^- for conversion electron, and e_p for photoelectron released in an external converter.

Reference	γ_1	γ_2	γ_3	γ_4	γ_5	γ_6	γ_7	γ_8	γ_9	γ_{10}
1								520 (γ)		
2	40.4 (e^-, e_p)							494 (e^-, e_p)		
3								497.9 (e_p)		
4	39.6 (e^-)	52.9 (e^-)		295 (e^-)				498 (e^-)		610.6 (e^-)
5								498 (e^-, e_p)		
6		58 (γ)		295 (γ)		357 (γ)		498 (γ, e^-)		611 (γ, e^-)
7								498 (e^-)		610 (e^-)
8		55 (γ)					440 (γ)	495 (γ)	555 (γ)	610 (γ)
9		55 (γ)		297 (e_p)	323 (e_p)	366 (e_p)		498 (γ)		610 (γ)
10	(38±2) (e^-)							496 (e^-, e_p)		
11		54 (γ)						496 (γ)		610 (γ)
12, 13		53 (γ)	65 (γ)	297 (γ)		362 (γ)	440 (γ)	498 (γ)	555 (γ)	610 (γ)

gamma ray appeared. Since the 297-keV gamma ray was found to be noncoincident with the 53-keV gamma ray, its coincident relationship with the 65-keV gate pulse was taken to be indirect evidence for the presence of a 65-keV gamma ray in the decay of Ru^{103}. Data relating to the 65-keV gate pulse are shown in Fig. 2(c).

In still another experiment utilizing two scintillation counters in coincidence, the K-shell internal conversion coefficient of the 53-keV gamma ray was measured. The gate pulse was supplied by the full energy peak of the 557-keV gamma ray. The K-shell x rays generated by internal conversion of the 53-keV gamma ray and the unconverted quanta at 53 keV were displayed in a crystal of NaI(Tl) of thickness 6 mm. Corrections were introduced to take into account effects of fluorescence yield ($\omega_K=0.78$ for Rh) and variation with quantum energy of the detection efficiency of the "display" crystal. Since the escape peak of the 53-keV gamma ray lay beneath the x-ray full energy peak, the area of the full energy peak at 53 keV was increased by 15.5%[18] and the area of the x-ray peak was decreased by the same absolute amount in taking the areas ratio for calculation of the K-shell conversion coefficient. Corrections were also carried out for the presence of preabsorbers before the display crystal. These absorbers between source and crystal stopped beta rays also emitted in the decay of Ru^{103}. Three separate experiments were performed to obtain the conversion coefficient, carbon being the intervening absorber in two cases and aluminum in the other. In either event, the correction factors applied were obtained by direct experimental observation. One of the sets of data obtained with carbon pre-absorption is shown in Fig. 3. The average value of the K-shell conversion coefficient obtained from the three aforementioned experiments is 1.77 ± 0.03.

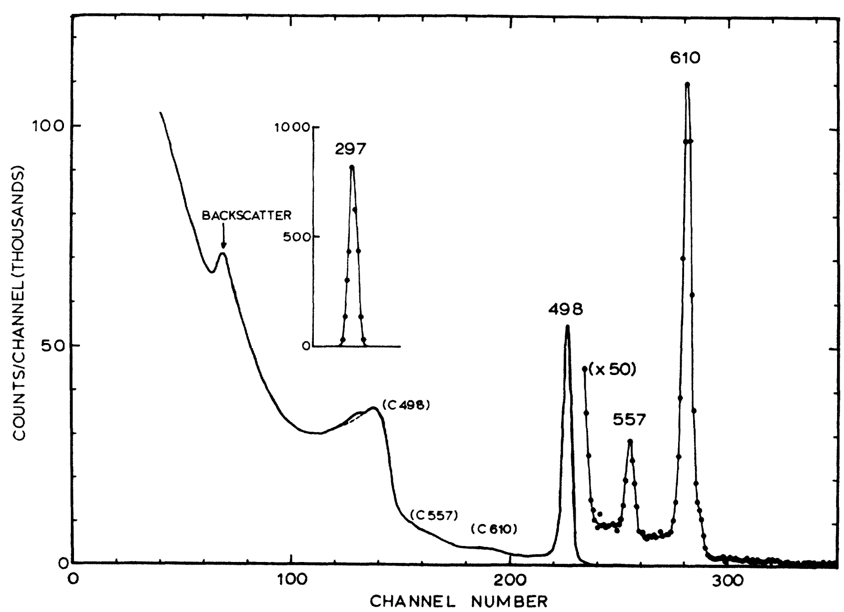

FIG. 1. Spectrum of single counts of the gamma rays of Ru^{103}. Energies are in keV, and "C" denotes Compton edges. The 53-keV gamma ray does not appear, because it was too heavily attenuated by the iron casing of the Ge(Li) detector.

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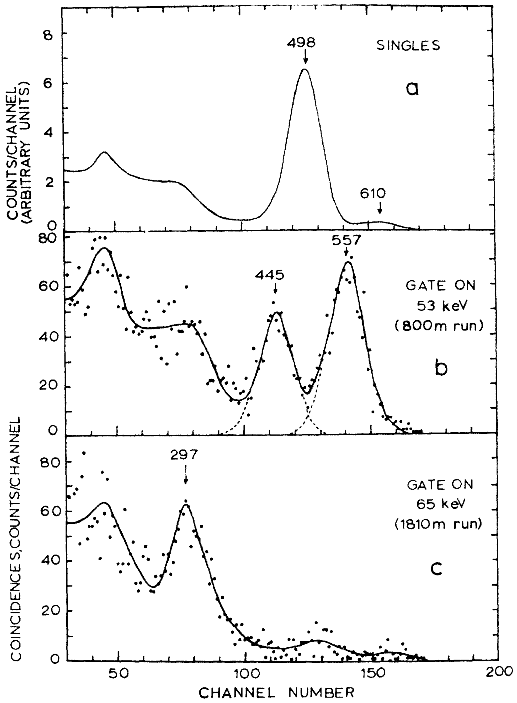

FIG. 2. (a) Spectrum of single counts in the display counter of the coincidence experiment. (b) Spectrum of gamma rays coincident with 53-keV gate pulse. (c) Spectrum of gamma rays coincident with 65-keV gate pulse.

III. DISCUSSION OF RESULTS

The nuclear level structure of Rh^{103} is shown in Fig. 4 in which is given the disintegration scheme of Ru^{103}. The spin of the ground state of Rh^{103} has a measured value[19] of $\frac{1}{2}$. This assignment is consistent with an orbital value of $p_{1/2}$ indicated by the shell model. The multipole order of the 40-keV transition has been determined to be $E3$ from measurement[20] of the

TABLE II. Energies and relative intensities of the gamma rays emitted in the decay of Ru^{103} as revealed by measurements presently discussed.

γ	Quantum energy (keV)	Relative intensity
γ_2	53	0.41[a]
γ_4	297	0.31
γ_7	445	0.40
γ_8	498	100.00
γ_9	557	0.87
γ_{10}	610	7.35

[a] The 53-keV gamma ray was readily observed in a Ge(Li) detector (depletion layer 4 mm thick), housed in aluminum. However, because all correction factors relating to this particular detector have not been fully determined, the relative intensity of the 53-keV gamma ray was estimated from the relative intensities of the 557- and 445-keV gamma rays, the measured value of α_K for the 53-keV gamma ray reported in this section, and theoretically calculated values of α_L and α_M (see Ref. 21 of the text).

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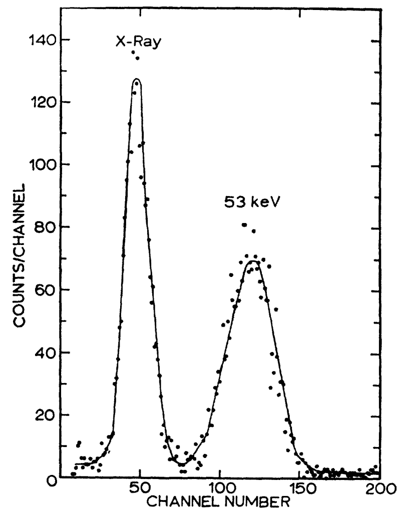

FIG. 3. Gamma rays and K-shell x rays coincident with the 557-keV gamma ray. The x rays arise from conversion of the 53-keV gamma rays. From these data, the K-shell conversion coefficient of the 53-keV transition is calculated.

half-life (57.5 min) of the 40-keV level following (p,p') excitation. Thus is indicated a spin value of $\frac{7}{2}+$ for the first excited state of Rh^{103}. The K-shell conversion coefficient of the 53-keV transition as presently reported ($\alpha_K=1.77\pm0.03$) suggests this transition to be essentially $M1$ in character, if comparison is made with values of α_K taken from the tables of Rose[21] $[\alpha_K(M1)=1.9;\alpha_K(E2)=8.5]$. Other recently reported values[12,13] of α_K are 1.99 and 2.74, which would suggest an $E2$-$M1$ admixture. However, whether pure or mixed, the multipole nature of the transition would be consistent with a spin-parity value of $\frac{9}{2}+$ for the 93-keV level. That the spin of the 93-keV state is large in comparison with that of the ground state is confirmed by the fact that it has not been excited in any nuclear reactions thus far reported. That the 53-keV transition is $M1$ is in agreement with the measured[22] half-life of the 93-keV

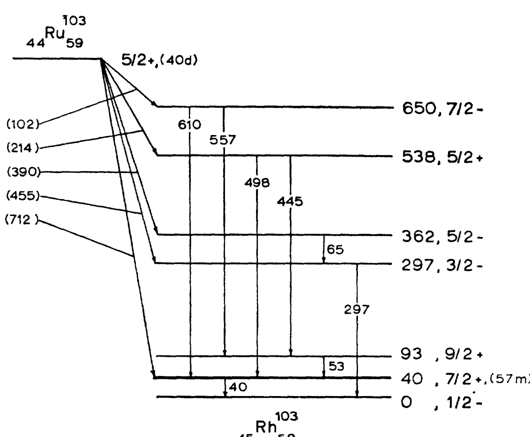

FIG. 4. Disintegration scheme of Ru^{103}, all energies in keV. For data concerning the beta spectra, see Ref. 13 of the text.

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state ($\tau_{1/2} \leq 10^{-9}$ sec). The levels at 297 and 362 keV have been given their assigned spin and parity assignments as a result of Coulomb excitation experiments.[14]

The levels at 538 and 650 keV in Rh^{103} have been established in energy by coincidence experiments.[8,13] The 610-keV gamma ray has a measured K-shell conversion coefficient[6] of 6×10^{-4} so that the transition may be regarded as $E1$. The parity of the 650-keV level is thus negative. Since the 557-keV gamma ray is of an intensity differing by less than one order of magnitude from that of the 610-keV gamma ray, it too may be considered to be $E1$, essentially ruling out the possibility that the 650-keV level have spin and parity $\frac{5}{2}-$.

The analysis of (d,p) stripping reactions[22] yields $\frac{5}{2}+$ for spin and parity of the ground state of Ru^{103}. Values of $\log ft$ for the beta spectra terminating at the energy states at 650 and 538 keV are 5.7 and 5.6, respectively.[13] Consistent with these values of $\log ft$ are spin-parity assignments of $\frac{7}{2}-$ and $\frac{5}{2}+$ for the 650- and 538-keV states. Additional evidence for assignment of positive parity to the 538-keV level is found in the fact that the K-shell conversion coefficient[2,7,10] of the 498-keV gamma ray suggests it to be $M1$ or $E2$. That spin and parity of the 538-keV level are $\frac{5}{2}+$ rather than $\frac{7}{2}+$ is supported by the fact that the 498-keV gamma ray and the 445-keV gamma ray differ so greatly in relative intensity, suggesting that these transitions do proceed according to different sets of selection rules.

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Proton Spectra from Reactions Induced by 30.5-MeV Alpha Particles*

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The (α,p) reaction has been studied at 30.5 MeV for the targets Al^{27}, Ti^{48}, V^{51}, Fe, Co^{59}, Ni^{58}, Ni^{60}, Ni^{61}, Ni^{62}, Cu^{63}, Cu^{65}, Zn^{67}, Nb^{93}, Mo, Rh^{103}, Pd, Cd^{113}, Cd^{114}, Sn^{119}, Sn^{120}, Sn^{124}, Ta^{181}, Pt^{195}, and Au^{197}. Proton evaporation spectra were measured at 30, 60, 90, 120, and 150° up to excitation energies of 25 MeV in the residual nucleus. The spectra have been compared with statistical-model predictions and the parameters a and T obtained. The lack of mass dependence of these parameters and the average low value of the level-density parameter $a=5.5$ MeV^{-1} add evidence for a nuclear-temperature anomaly. The anomaly is discussed in terms of recent intermediate-resonance models.

1. INTRODUCTION

THE statistical model is supported by a large body of experimental information accumulated over the past decade. The model has been widely applied to nuclear-reaction studies involving medium-energy neutrons, protons, alpha particles and to some extent He^3, deuterons and heavy ions as bombarding particles on intermediate and heavy nuclei ($A>25$). A comprehensive review of the existing experimental support for the statistical model has been given by Bodansky.[1] That a wide range of measurements of yields, level spacings and emission spectra can be successfully accounted for in terms of the nuclear level density is the most compelling evidence in support of the statistical model.

An understanding of the magnitude of the level density and its dependence upon excitation energy and mass is central to the successful application of the statistical model. The dependence of the level density on excitation energy and mass is influenced by the details of the assumed nuclear model and is parametrized by the nuclear-temperature or Fermi-gas-model level-density parameter a. The excitation-energy dependence of the level-density parameter has been the subject of numerous investigations of which the presently reported study is an additional example.

A comprehensive survey of the mass dependence of the parameter a have been made by Lang[2] and Erba,

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