Internal-Conversion-Electron Study of the Decay of Ru^{103}

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The β decay of Ru^{103} (39.6 d) has been investigated with an iron-core, $\pi\sqrt{2}$ double-focussing β-ray spectrometer. The internal-conversion-electron spectrum revealed the presence of γ rays of 609.89(24), 556.85(22), 496.88(16), 443.85(15), 294.88(16), 53.11(3), and 39.55(4) keV. No new lines with an intensity greater than 1.6% of the $497K$ line were found. The $67K$ line was found to have an intensity less than 0.17%, and the $322K$ and $362K$ lines an intensity less than 0.3%, of the $497K$ line. Limitations on the multipolarities and mixing ratios of some of the transitions have been determined through K/L- and L-subshell ratios, and through internal-conversion-coefficient measurements. The multipolarities obtained for the seven observed transitions were compared with γ-γ angular-correlation results. This resulted in the spin-parity assignments of $\frac{7}{2}^+$, $\frac{9}{2}^+$, and $\frac{7}{2}^-$ for the 39.55(4)-, 92.66(5)-, and 649.48(24)-keV states, respectively. The 536.47(16)-keV level is shown to have a spin parity of either $\frac{3}{2}^+$ or $\frac{7}{2}^-$.

INTRODUCTION

THE nucleus Ru^{103} undergoes β decay with a half-life of 39.6 days[1] to Rh^{103m} and other levels in Rh^{103}. The existence of an isomeric level in Rh^{103} at 40-keV excitation energy has been known for a long time. The isomeric transition has been assigned an $E3$ multipolarity by Goldhaber and Sunyar[2] on the basis of an empirical relation between K/L ratios and lifetimes. Jones and Phillips[3] have also presented evidence that they have observed $E3$ Coulomb excitation of the isomeric level by the bombardment of stable Rh^{103} targets with protons of energies 700 to 1200 keV.

The presently accepted level scheme of Rh^{103} was proposed by Saraf[4] as a result of his coincidence studies of the β decay of Ru^{103} and the electron-capture decay of Pd^{103} ($T_{1/2}=17$ days). In addition to the isomeric state, he assigned levels at 93, 300, 365, 535, and 650 keV. The level ordering can be seen in Fig. 7. Of the 21 possible γ-ray transitions between the seven levels of Rh^{103} populated in the β decay of Ru^{103}, only some 10 transitions have been reported. There is a general agreement on the existence of γ rays with energies of 53, 497, and 610 keV. However, conflicting reports on the existence of γ rays with energies of 67, 295, 322, 362, 444, and 557 keV are present in the literature.[4–9]

* An element of the Office of Aerospace Research, U. S. Air Force.

[1] *Nuclear Data Sheets*, edited by K. Way *et al.* (National Academy of Sciences–National Research Council, Washington 25, D. C.), NRC 61-2-91.

[2] M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).

[3] G. A. Jones and W. R. Phillips, Proc. Phys. Soc. (London) **239A**, 487 (1957).

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[7] S. I. H. Naqvi and B. G. Hogg, Phys. Rev. **128**, 357 (1962).

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[9] V. R. Potnis, E. B. Nieschmidt, C. E. Mandeville, L. D. Ellsworth, and G. P. Agin, Phys. Rev. **146**, 883 (1966).

Kuhn and Woodgate[10] have determined the ground-state spin of Rh^{103} to be $\frac{1}{2}$ from atomic-beam absorption methods and have estimated the magnetic moment of the ground state to be (-0.10 ± 0.03) nuclear magnetons. These values for the spin and magnetic moment agree with the Schmidt limit for a $p_{1/2}$ proton. Consequently, the ground-state configuration of the last seven protons of Rh^{103} can be considered to be $(5g_{9/2})^6\, 3p_{1/2}$. Such an assignment would require a negative parity for this state. The ground-state spin and parity of Ru^{103} have been tentatively assigned $\frac{5}{2}^+$ by Mason *et al.*[11] on the basis of their study of the $Ru^{102}(d,p)Ru^{103}$ stripping reaction at 8.9-MeV incident energy. Utilizing Butler stripping theory, they find that the resulting angular distribution of protons can be assigned values of $l_n=2$, 3, or 4, depending on the value of the interaction radius used in the analysis. From various arguments, Mason *et al.* prefer $l_n=2$ and $J^\pi=\frac{5}{2}^+$.

The metastable state at 40-keV excitation energy has an assigned spin parity of $\frac{7}{2}^+$ solely as a result of the $E3$ character of the 40-keV isomeric transition to the ground state. Goldhaber and Sunyar[2] suggest that this level consists of a $(3p_{1/2})^2{}_0(5g_{9/2})^5{}_{7/2}$ configuration for the last seven protons. Such a configuration might explain the observed large log ft value for the supposedly allowed β transition to this level from Ru^{103}. No direct measurement of the spin of this level has been reported. The $M1$ character of $\alpha_K(53)$ [4,8,9] and the lack of a β branch to the 93-keV level has been used to suggest $J^\pi=\frac{9}{2}^+$ for this level.[8]

Suggested J^π assignments for the levels at 650 and 536 keV include $\frac{5}{2}^+$, $\frac{7}{2}^+$, $\frac{9}{2}^+$ or $\frac{7}{2}^-$ for the upper level and $\frac{5}{2}^+$, $\frac{7}{2}^+$ or $\frac{9}{2}^+$ for the lower level.[4,7–9,12,13]

[10] H. Kuhn and G. K. Woodgate, Proc. Phys. Soc. (London) **A64**, 1090 (1951).

[11] P. Mason, F. C. Flack, and G. Parry, Proc. Phys. Soc. (London) **73**, 138 (1959).

[12] F. C. Flack and P. Mason, Proc. Phys. Soc. (London) **71**, 247 (1958).

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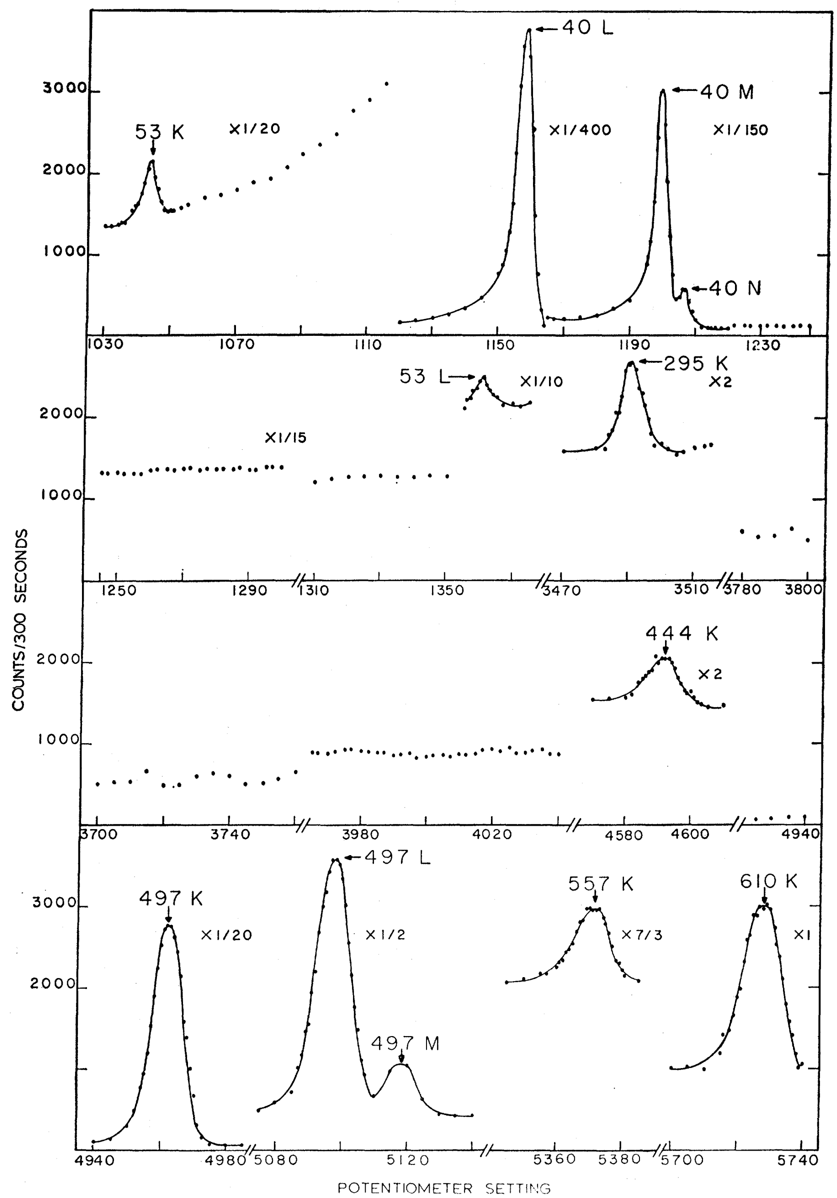

FIG. 1. Partial internal-conversion-electron spectrum showing the major observed lines and regions of the spectrum where the *67K*, *322K*, and *362K* lines are expected.

The 295- and 362-keV γ rays have been observed in Coulomb-excitation experiments by Heydenburg and Temmer[14] and by McGowan and Stelson.[15] The latter authors assign $\frac{3}{2}^-$ and $\frac{5}{2}^-$ to the 295- and 362-keV levels, respectively, on the basis of γ-ray angular distribution and polarization measurements. These assignments are consistent with a rotational interpretation for these levels.

The present investigation of the internal-conversion-electron spectrum from the decay of Ru^{103} to Rh^{103} was undertaken for the following reasons: (1) to provide an independent check on the existence of the controversial γ-ray transitions of 67, 295, 322, 362, 444, and 557 keV, (2) to make accurate energy and intensity measurements, (3) to measure K/L and $L_1/L_2/L_3$ ratios wherever possible in order to determine transition multipolarities.

EXPERIMENTAL TECHNIQUES AND RESULTS

1. Source Preparation

The primary source activity was obtained commercially from Oak Ridge National Laboratory as $RuCl_3$ in HCl solution. The source material was carrier free except for about 10% Ru^{106} present as an impurity.

[14] N. P. Heydenburg and G. M. Temmer, Phys. Rev. **95**, 861 (1954).

[15] F. K. McGowan and P. H. Stelson, Phys. Rev. **99**, 112 (1955); **99**, 127 (1955); **109**, 901 (1958).

TABLE I. Energy and intensity results.

Transition	Electron energy (keV)	Transition energy (keV)	Relative electron intensity %	Relative γ intensity[a] %	α_K
53K	29.89(3)	53.11(3)	107(16)	0.38(3)	1.84[b]
40L	36.55(4)	39.55(4)[c]	11 800(1800)	0.063(5)	1280(260)
40M	39.08(4)	39.59(4)[d]	2480		
53L	49.81(7)	53.22(7)[e]	12.6(13)		0.236[b]
295K	271.66(16)	294.88(16)	0.85(9)	0.24(2)	0.024(4)
444K	420.63(15)	443.85(15)	0.68(4)	0.40(3)	0.012(2)
497K	473.66(16)	496.88(16)	100(6)	100	0.007(1)
497L	493.35(20)	496.76(20)[e]	11.8(7)		
557K	533.63(22)	556.85(22)	1.03(6)	0.90(6)	0.008(1)
610K	586.67(24)	609.89(24)	3.98(24)	6.1(4)	0.0045(7)

[a] Relative γ intensities from Nieschmidt (Ref. 24).
[b] The K and L conversion coefficients for the 53-keV transitions are the theoretical $M1$ coefficients used to normalize the intensity data for the determination of the other conversion coefficients.
[c] From L_3 line.
[d] From M_2+M_3 line.
[e] From L_1 line.

The acid was removed by evaporating the stock solution to dryness. The resulting $RuCl_3$ was redissolved in a small amount of distilled water. This process was repeated several times to remove the acid content. The final source with an area of 4×20 mm^2 was prepared by drying the resulting $RuCl_3$ solution on an aluminized-Mylar-foil backing.

With the 4-mm wide source and a 2-mm wide detector slit, the momentum resolution obtained was 0.24% for electron lines with energies greater than 150 keV. Source thickness effects caused a broadening of the lower energy lines such that the observed momentum resolution was 0.44% for the 53K line (30-keV electron energy) and 0.40% for the 53L line (50-keV electron energy). The 53L line was studied at better resolution by washing the source with distilled water and masking the width to 2 mm by means of 0.005-in. thick copper slits. In this way, a resolution of 0.25% was obtained for the 53L_1 line. The 40L line was studied at a momentum resolution of 0.19% with a 1-mm detector slit opening and a 1-mm source slit opening.

2. Apparatus

A 50-cm mean-radius–double-focussing β-ray spectrometer with an iron core was used for the studies of the internal-conversion-electron spectrum. This instrument has been described recently by Hennecke *et al.*[16] The electron detector was a commercially made Si(Li) solid-state detector with a rectangular cross section of 5×25 mm^2 and a 2-mm depth. The detector was cooled by means of a liquid-nitrogen cryostat. The typical energy resolution obtained with the detection system was 8–10 keV full width at half maximum (FWHM).

3. Energy and Intensity Measurements

The major portions of the conversion-electron spectrum obtained with the 4-mm wide Ru^{103} source are given in Fig. 1. This figure shows the observed conversion lines attributed to transitions in Rh^{103} together with three regions which were scanned several times in order to observe the 67K, 322K, and 362K lines. The energies and relative intensities of the conversion lines studied are given in Table I. Upper limits obtained for the intensities of undetected transitions in the electron energy range from 40 to 760 keV are presented in Table II. The final set of transition energies and the resulting level energies are summarized in the level scheme, Fig. 7.

The energies of the Ru^{103} conversion lines were determined using the accurately known momenta of the conversion lines of Ba^{133} and Cs^{137}.[16,17] The intersection between the extrapolated high- and low-energy edges of the conversion line was used for momentum definition.

Relative conversion-line intensities were determined by measuring the area under the line with a planimeter, normalizing this area with the appropriate momentum value, and correcting for the detection efficiency of the solid-state detector. Details of the detector-efficiency determination can be found in Ref. 16. Decay corrections were also made where necessary.

Several sources of error were considered for the relative-intensity measurements. The detection efficiency decreased rapidly for energies below 50 keV, e.g., ϵ(50 keV)$=75\%$ and ϵ(30 keV)$=53\%$. It is felt that the absolute detection efficiency is known to within an uncertainty of 10% at 30 keV, 5% at 50 keV, and 3% above 60 keV. For some of the weaker lines, 2–5% errors had to be included for counting statistics. For the lines with energies below 50 keV, source-thickness effects and electron backscattering in the source and backing made it difficult to determine the contribution of the low-energy tails of the lines with an accuracy better than 10% of the total line intensity.

[16] H. J. Hennecke, J. C. Manthuruthil, O. Bergman, and C. R. Cothern, Phys. Rev. 159, 955 (1967).

[17] K. Siegbahn, in *Alpha-, Beta-, and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (North-Holland Publishing Company, Amsterdam, 1965), p. 198.

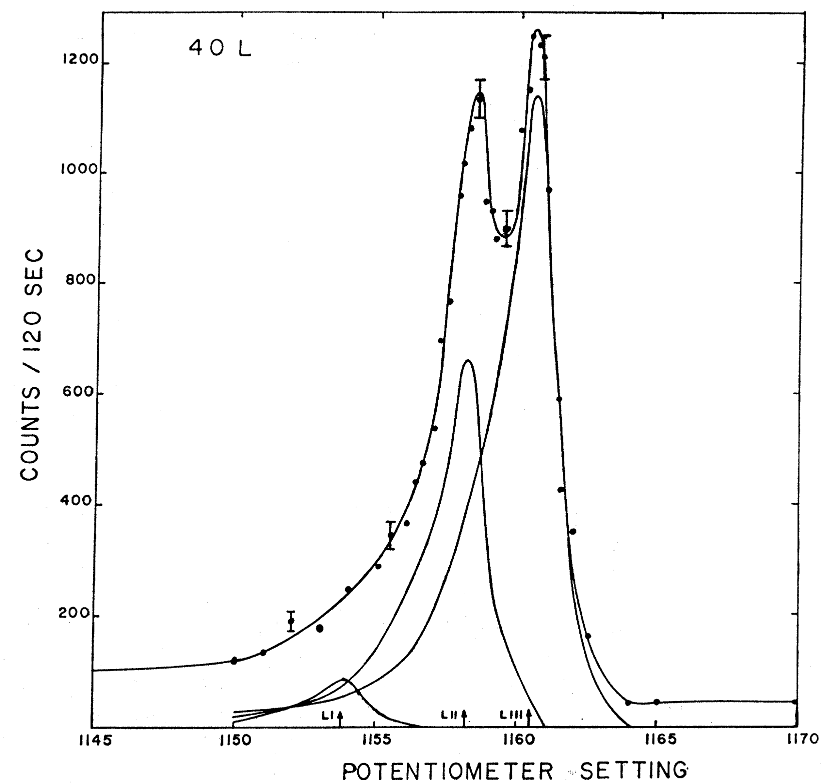

FIG. 2. 40L line for the isomeric transition in Rh^{103}. Experimental momentum resolution (including source thickness effects) is 0.19%. Also shown are the three L-subshell lines (solid curves) and the composite L line (solid curve through the data points). The solid curves were obtained by least-square techniques with $\chi^2=1.72$ and $|\delta|=0.08$ for $M4/E3$ mixing. Conversion coefficients of Sliv and Band (see Ref. 18) were used in this calculation.

4. L-Subshell Measurements

Careful measurements were made of the 40L and 53L lines at momentum resolutions (including source thickness effects) of 0.19% and 0.25%, respectively. These resolutions were not sufficient to resolve completely the individual L-subshell lines, but were good enough to indicate the structure of the composite line. The L lines were analyzed with the computer code described by Hennecke *et al.*[16] Briefly, the procedure is as follows: The computer code constructs the composite line using theoretical L-subshell conversion coefficients, the $(L+1)$-pole/L-pole amplitude mixing ratio δ^2, the L_1-L_2-L_3 separation determined from the atomic binding energies, and a reference line shape obtained by an iterative procedure. The normalization factor for this calculated composite line together with two parameters defining a linear background are then determined by least-square techniques. The resulting goodness of fit is checked by examining the value of Q^2 defined as

$$Q^2=\frac{1}{n-5}\sum_{i=1}^{n}\frac{[W(B_i)-W^*(B_i)]^2}{W(B_i)}.$$

Here $W(B_i)$ is the experimental counting rate at a given spectrometer field setting B_i, and $W^*(B_i)$ is the corresponding value for the composite line and background computed as mentioned above. Here it is assumed that $W(B_i)$ follows Poisson statistics and that the reference line shape is known exactly. Of the five degrees of freedom subtracted from the total number of data points n, three are for the normalization constants mentioned above, one is for the mixing ratio $|\delta|$, and one is for the magnetic field setting B_1 of the L_1 line. The value of $|\delta|$ is varied until a minimum value of Q^2 is found; this minimum value of Q^2 is referred to as χ^2. The confidence limits for the mixing ration $|\delta_1|\leq|\delta|$

TABLE II. Intensity limits for weak conversion lines from the decay of Ru^{103}.

Electron energy range (keV)	γ-ray energy range[a] (keV)	Intensity limit[b] (% of 497K)
40.4– 47.6(67K)[c]	63.6– 70.8	0.17
46.2–121.8	69.4–145.0	1.6
121.8–149.8	145.0–173.0	1.4
149.8–155.3	173.0–178.5	1.3
155.3–164.1	178.5–187.5	1.2
164.1–179.8	187.5–203.0	1.0
179.8–187.9	203.0–211.1	0.8
187.9–201.6	211.1–224.8	0.6
201.6–206.7	224.8–229.9	0.5
206.7–211.6	229.9–234.8	0.4
211.6–221.3	234.8–244.5	0.3
221.3–419.3	244.5–441.5	0.3
423.3–740.3	446.5–763.5	0.3
740.3–759.0	763.5–782.0	0.4

[a] K-atomic binding energy added to electron energies.
[b] Intensity limit $=300N^{1/2}/N_{497K}$, where N is the average count rate in the energy range and N_{497K} is the peak count rate for the 497K line. The tabulated limit applies to the given range except within ±3 keV of the lines listed in Table I.
[c] The presence of the L, M, and N lines of the 40-keV transition restricted the lower energy end of the search for the 67K line.

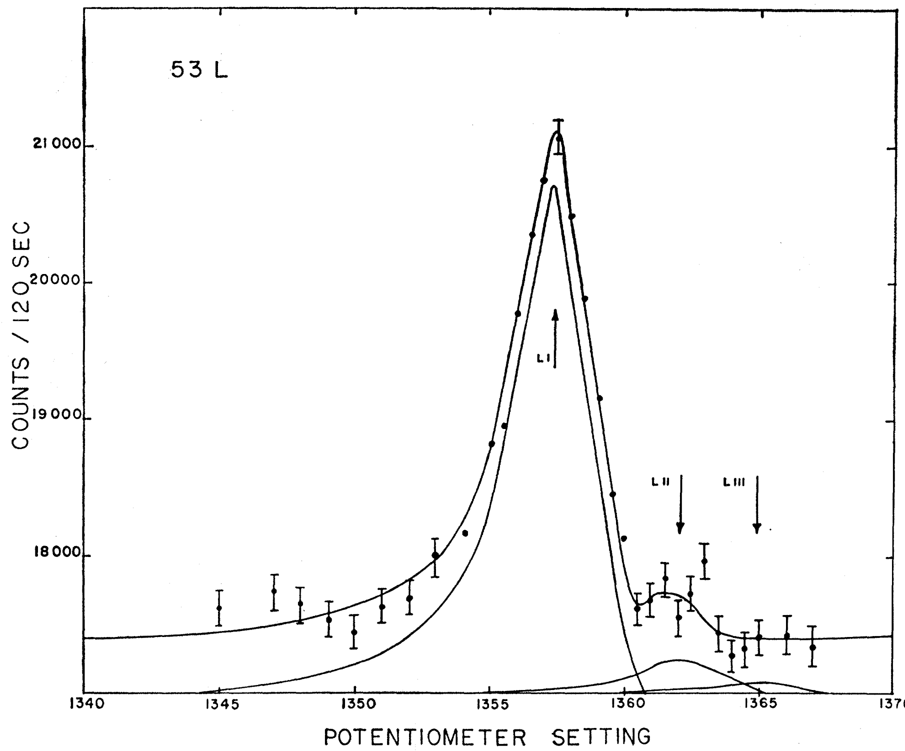

FIG. 3. 53L line at an experimental momentum resolution of 0.25%. The solid curves correspond to a least-squares fit with $\chi^2=1.09$ and $|\delta|=0$ for $E2/M1$ mixing. Conversion coefficients of Sliv and Band (see Ref. 18) were used in this calculation.

$\leq|\delta_2|$ arising from statistical considerations only are determined by the condition

$$Q^2(|\delta_i|)=\chi^2+1/(n-5).$$

Here i has the value 1 or 2 corresponding to the two solutions near the minimum of the quadratic function $Q^2(|\delta|)$. This analysis technique assumes that the reference line shape and the theoretical conversion coefficients are known exactly. The sensitivity of the calculation to these quantities was tested by trying various line shapes and two sets of conversion coefficients.[18,19]

The data for the 40L and 53L lines are shown in Figs. 2 and 3. The χ-squared analysis of this data is presented in Figs. 4 and 5, and the resulting mixing ratios are given in Table III. Two solutions with χ-squared fits better than the 0.1% confidence limits were found for the 40L line; viz., for $M4/E3$ mixing and $E5/M4$ mixing. We consider the $M4$ admixture to the $E3$ solution to be an indication of our inability to obtain a better reference line shape by an iterative process for this data due to the rather large L_2 component. The data for the 53L line can only be fitted by considering mixings of the type $E2/M1$.

In Table III, we have presented the mixing ratios obtained by using the conversion coefficient tables of both Sliv and Band,[18] and Rose[19]; the difference is about 6%. The accuracy of these tables are presently being investigated at several laboratories by measuring L-subshell ratios of pure $E2$ transitions. Recently reported measurements[20–22] have shown that L_1/L_2 and L_1/L_3 ratios are systematically larger than the theoretical values by an average of about 5–6%, whereas the experimental L_2/L_3 ratios agree with the corresponding theoretical ratios to $\leq 2\%$. Very recently Bhalla[23] has calculated internal conversion coefficients using a relativistic Hartree-Fock potential in the Slater-exchange approximation with the inclusion of static finite-nuclear-size effects. These new calculations differ from both of the two previous major tabulations. Further experiments would be useful to test the accuracy of these latest theoretical conversion coefficients.

TABLE III. Multipolarity mixings from L-subshell ratios.

Transition	Resolution %	Multipolarity mixings $\lvert\delta\rvert$ Rose[a]	Sliv-Band[b]	
39.55	0.19	0.075 ± 0.005	0.081 ± 0.005	$M4/E3$
			0.31 ± 0.01	$E5/M4$
53.11	0.25	≤ 0.048	≤ 0.045	$E2/M1$

[a] See Ref. 19.
[b] See Ref. 18.

[18] I. M. Band and L. A. Sliv in *Alpha-, Beta-, Gamma-Ray Spectroscopy*, edited by K. Siegbahn (North-Holland Publishing Company, Amsterdam, 1965), Appendix 5.

[19] M. E. Rose, *Internal Conversion Coefficients* (North-Holland Publishing Company, Amsterdam, 1958).

[20] P. Erman, G. T. Emery, and M. C. Perlman, Phys. Rev. **147**, 858 (1966).

[21] S. E. Karlsson, I. Andersson, O. Nilsson, G. Malmsten, C. Nordling, and K. Siegbahn, Nucl. Phys. **89**, 513 (1966).

[22] W. Gelletly, J. S. Geiger, and R. L. Graham, Phys. Rev. **157**, 1043 (1967).

[23] C. P. Bhalla, Phys. Rev. **157**, 1136 (1967).

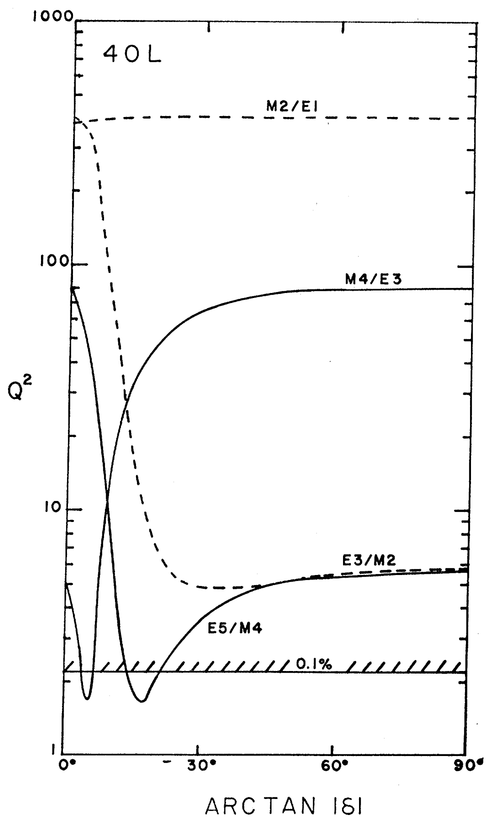

FIG. 4. Q^2 versus arctan $|\delta|$ for the $40L$ line with momentum resolution of 0.19%. The 0.1% confidence limit is also shown.

5. Internal Conversion Coefficient

Relative K-shell conversion coefficients were calculated from the present relative electron-intensity measurements plus the recent relative γ-ray intensities of Nieschmidt.[24] The conversion coefficients were normalized under the assumption that the 53-keV transition is of pure $M1$ multipolarity. This assumption is supported by our L-subshell measurements and the $\alpha_K(53)$ measurement of Potnis *et al.*[9] The normalization constant was calculated from both the $53K$ and $53L$ intensities together with the theoretical $M1$-conversion coefficients $\beta_K(53)=1.84$ and $\beta_L(53)=0.236$.[18] The weighted mean of the two normalization constants calculated in this way had an error of 11%. The mean-square error for each α_K was determined by adding in quadrature the uncertainties in our K-conversion relative intensities, the uncertainty in the normalization constant, and the uncertainties in the γ-ray intensities of Ref. 24.

The γ-ray relative intensities of Nieschmidt[24] are reproduced in column 5 of Table I. The values of α_K determined in the present work are given in column 6 of Table I and in Fig. 6. The theoretical variation[18] of α_K with transition energy and multipolarity for $Z=45$ is also shown by the curves of Fig. 6.

[24] E. B. Nieschmidt (private communication).

Our measurements of $\alpha_K(497)=0.007\pm0.001$ agrees within the quoted errors with the previously reported values of $\alpha_K(497)=0.0055\pm0.0003$ [25] and 0.006.[26] Using theoretical conversion coefficients[18] together with $\delta(295)=-0.17\pm0.01$ $(E2+M1)$ [15] one can calculate $\alpha_K(295)=0.0168\pm0.0001$. This value can be compared to our direct measurement of $\alpha_K(295)=0.024\pm0.004$.

DISCUSSION

The results of the present investigation together with those of previous investigations are shown in Fig. 7. The β-decay endpoint energies given have been calculated from our energy measurements together with the value (112±6) keV obtained by Mukerji *et al.*[8] for the transition to the 650-keV level. The β-branching intensities and log ft values for the transitions to the 295- and 362-keV levels were calculated from the present measurements together with the data of McGowan and Stelson,[15] while the rest are due to Mukerji *et al.*

Previous investigators have classified the 40-keV transition to be $E3$ from an empirical relationship between K/L values and lifetimes.[2] One of the solutions

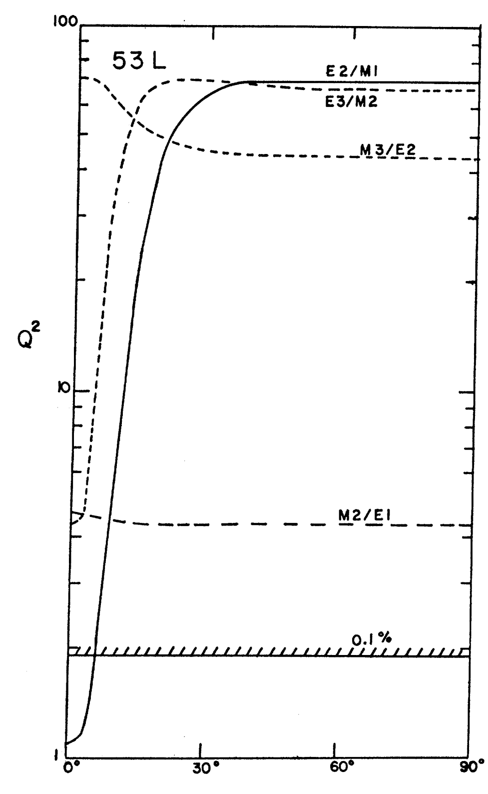

FIG. 5. Q^2 versus arctan $|\delta|$ for the $53L$ line with a momentum resolution of 0.25%.

[25] J. Y. Mei, C. M. Huddleston, A. C. G. Mitchell, Phys. Rev. **79**, 429 (1950).

[26] V. S. Shpinel and G. A. Kuznetsova, Zh. Eksperim. i Teor. Fiz. **30**, 231 (1956) [English transl.: Soviet Phys.—JETP **3**, 216 (1956)].

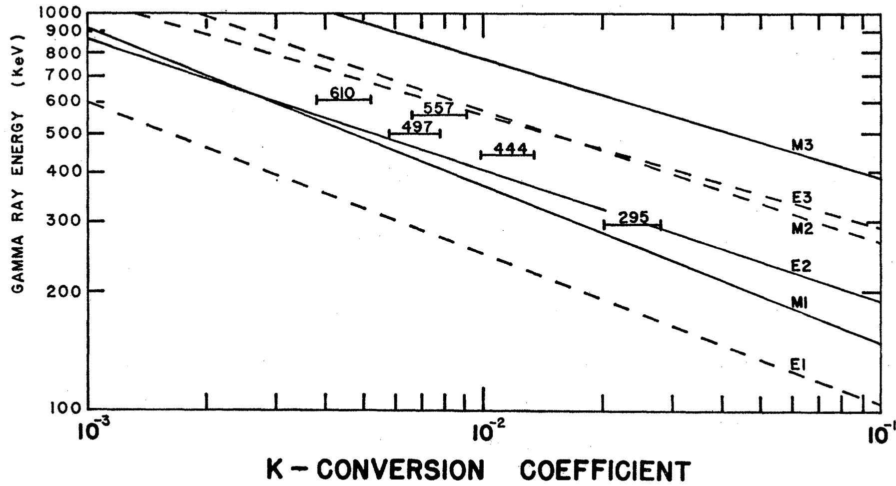

FIG. 6. Theoretical variation of K-conversion coefficients with energy and multipolarity for $Z=45$ as obtained from the tabulation of Sliv and Band (see Ref. 18). The results of the present K-conversion coefficient measurements are also shown.

from the present L-subshell ratios agrees with this assignment as does the total $40L$ conversion coefficient given in Table I. The other solution for an $E5/M4$ mixture would be inconsistent with the present $40L$ conversion-coefficient measurement as well as with the known (57.5 ± 0.5) min half-life for this level.[3]

The 53-keV transition has generally been accepted as an $M1$ transition. However, conflicting K-conversion-coefficient measurements have been reported: $\alpha_K=1.2\pm0.3$,[4] 2.74 ± 0.03,[8] and 1.77 ± 0.03.[9] Our L-subshell results would limit the $E2$ admixture to be $|\delta|_{53}\leq 0.02$, a fact which would give the value $\alpha_K=1.84$ from the theoretical conversion coefficients.[18] The value of $K/L=8.5\pm0.9$ from our intensity measurements supports the $M1$ classification but with much broader error limits.

Definite spin-parity assignments of $\frac{1}{2}^-$, $\frac{3}{2}^-$, and $\frac{5}{2}^-$ have been made for the ground state and the 295- and 362-keV levels. The present L-subshell and total L-conversion coefficient measurements support the $\frac{7}{2}^+$ assignment for the 40-keV level. The combination of the present α_K measurements together with recent

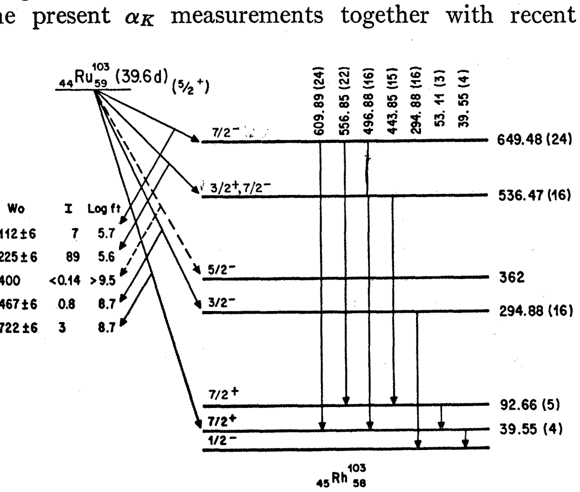

FIG. 7. Decay scheme of Ru[103]. All energies are in keV.

557–53 and 444–53 γ-γ angular-correlation measurements[12,13,27] can be used to assign spin and parities to the 93-, 538-, and 650-keV levels.

The three sets of data available for the 557–53 γ-γ angular correlation agree within the reported error limits; viz., $A_2=-0.129\pm0.020$,[12] $A_2=-0.152+0.011$,[13] and $A_2=-0.131\pm0.014$.[27] We have analyzed with contour plot techniques the most recent data of George *et al.*[27] together with the $M1$ restriction for the 53-keV transition and the present α_K measurement for the 557-keV transition. The results are presented in Table IV. From the table, it is clear that of the many possibilities considered the data are consistent only with the two spin-parity sequences of $\frac{3}{2}^-\rightarrow\frac{5}{2}^+$ or $\frac{7}{2}^-\rightarrow\frac{7}{2}^+$ for the 650- and 93-keV levels. Both the solutions require a negative parity for the 650-keV level. Thus the 610-keV transition must be $E1+M2$ to be consistent with the $\alpha_K(610)$ measurement. However, this fact limits the spin and parity of 650-keV level to be $\frac{7}{2}^-$. A $\frac{7}{2}^-$ assignment for the 650-keV level would then require a $\frac{7}{2}^+$ assignment for the 93-keV level.

The three sets of data for the 444–53 γ-γ angular correlation do not agree very well: viz., $A_2=0.00\pm0.02$,[12] $A_2=0.049\pm0.013$,[13] and $A_2=0.121\pm0.060$.[2] Again, we have analyzed the most recent data of George *et al.*[27] together with the $M1$ restriction for the 53-keV transition and the present α_K measurement for the 444-keV transition. The results are presented in Table V. It is clear from this table, together with the $\frac{7}{2}^+$ assignment for the 93-keV level, that the 536-keV level can only have a spin-parity assignment of $\frac{3}{2}^+$ or $\frac{7}{2}^-$. The present measurement of $\alpha_K(497)$ is consistent with both these assignments as can be seen from Fig. 6.

From the deuteron-stripping results of Mason *et al.*,[11] the possible spin and parity assignments for the Ru[103] ground state are $\frac{3}{2}^+$, $\frac{5}{2}^+$, $\frac{5}{2}^-$ or $\frac{7}{2}^-$. A $\frac{3}{2}^+$ assignment for

[27] M. C. George, John W. Kane and Ambuj Mukerji (private communication).

Table IV. Comparison of the multipolarity mixing ratio of the 557-keV transition.

Spin sequence for the levels 650–93–40	δ^2_{557}: 557–53 correlation[a]	δ^2_{557}: $\alpha_K(557)$[b]	Possible assignment
$\frac{3}{2}-\frac{5}{2}-\frac{7}{2}$	$1.2\leq\delta_1^2\leq2.9$	$E1+M2$	
	$0.6\leq\delta_2^2\leq6.2$	$1.3\leq\delta^2\leq4.6$	Yes
$\frac{3}{2}-\frac{7}{2}-\frac{7}{2}$	No solution	$E2+M3$	
		$0.13\leq\delta^2\leq0.27$	No
$\frac{5}{2}-\frac{5}{2}-\frac{7}{2}$	No solution	$E1+M2$	
		$1.3\leq\delta^2\leq4.6$	No
$\frac{5}{2}-\frac{7}{2}-\frac{7}{2}$	$\delta_1^2\leq0.002$	$E1+M2$	
	$20\leq\delta_2^2\leq34$	$1.3\leq\delta^2\leq4.6$	No
$\frac{5}{2}-\frac{9}{2}-\frac{7}{2}$	$\delta_1^2\leq0.005$	$E2+M3$	
	$\delta_2^2\geq200$	$0.13\leq\delta^2\leq0.27$	No
$\frac{7}{2}-\frac{5}{2}-\frac{7}{2}$	No solution	$E1+M2$	
		$1.3\leq\delta^2\leq4.6$	No
$\frac{7}{2}-\frac{7}{2}-\frac{7}{2}$	$0.8\leq\delta_1^2\leq1.5$	$E1+M2$	
	$49\leq\delta_2^2\leq\infty$	$1.3\leq\delta^2\leq4.6$	Yes
$\frac{7}{2}-\frac{9}{2}-\frac{7}{2}$	$0.14\leq\delta_1^2\leq0.23$	$E1+M2$	
	$12\leq\delta_2^2\leq26$	$1.3\leq\delta^2\leq4.6$	No
$\frac{9}{2}-\frac{5}{2}-\frac{7}{2}$	No solution	$E2+M3$	
		$0.13\leq\delta^2\leq0.27$	No
$\frac{9}{2}-\frac{7}{2}-\frac{7}{2}$	$0.006\leq\delta_1^2\leq0.015$	$E1+M2$	
	$\delta_2^2\geq1600$	$1.3\leq\delta^2\leq4.6$	No
$\frac{9}{2}-\frac{9}{2}-\frac{7}{2}$	$\delta_1^2\leq0.006$	$E1+M2$	
	$0.5\leq\delta_2^2\leq1.0$	$1.3\leq\delta^2\leq4.6$	No

[a] The angular-correlation data was taken from Ref. 25 with $A_2=-0.131\pm0.014$ and $A_4=-0.046\pm0.050$. The 53-keV transition was assumed to be pure $M1$.
[b] From the present measurement of $\alpha_K(555)=0.008\pm0.001$ together with the theoretical α_K values of Ref. 18.

Table V. Comparison of the multipolarity mixing ratio for the 444-keV transition.

Spin sequence for the levels 536–93–40	δ^2_{444}: 444–53 correlation[a]	δ^2_{444}: $\alpha_K(444)$[b]	Possible assignment
$\frac{3}{2}-\frac{5}{2}-\frac{7}{2}$	$0.002\leq\delta^2\leq8$	$E1+M2$	
		$0.7\leq\delta^2\leq1.5$	Yes
$\frac{3}{2}-\frac{7}{2}-\frac{7}{2}$	$0.003\leq\delta^2\leq0.15$	$E2+M3$	
	$4\leq\delta^2\leq59$	$0.05\leq\delta^2\leq0.12$	Yes
$\frac{5}{2}-\frac{5}{2}-\frac{7}{2}$	$1.7\leq\delta^2\leq6.3$	$E1+M2$	
		$0.7\leq\delta^2\leq1.5$	Maybe
$\frac{5}{2}-\frac{7}{2}-\frac{7}{2}$	$0.06\leq\delta_1^2\leq0.18$	$E1+M2$	
	$27\leq\delta_2^2\leq910$	$0.7\leq\delta^2\leq1.5$	No
$\frac{5}{2}-\frac{9}{2}-\frac{7}{2}$	No solution	$E2+M3$	
		$0.05\leq\delta^2\leq0.12$	No
$\frac{7}{2}-\frac{5}{2}-\frac{7}{2}$	$\delta_1^2\leq0.006$	$E1+M2$	
	$27\leq\delta_2^2\leq94$	$0.7\leq\delta^2\leq1.5$	No
$\frac{7}{2}-\frac{7}{2}-\frac{7}{2}$	$0.001\leq\delta_1^2\leq0.11$	$E1+M2$	
	$1.4\leq\delta_2^2\leq5.3$	$0.7\leq\delta^2\leq1.5$	Yes
$\frac{7}{2}-\frac{9}{2}-\frac{7}{2}$	$\delta_1^2\leq0.03$	$E1+M2$	
	$8\leq\delta_2^2\leq72$	$0.7\leq\delta^2\leq1.5$	No
$\frac{9}{2}-\frac{5}{2}-\frac{7}{2}$	$0.4\leq\delta^2\leq340$	$E2+M3$	
		$0.05\leq\delta^2\leq0.12$	No
$\frac{9}{2}-\frac{7}{2}-\frac{7}{2}$	$0.04\leq\delta_1^2\leq0.25$	$E1+M2$	
	$2.5\leq\delta_2^2\leq10.2$	$0.7\leq\delta^2\leq1.5$	No
$\frac{9}{2}-\frac{9}{2}-\frac{7}{2}$	$0.9\leq\delta^2\leq\infty$	$E1+M2$	
		$0.7\leq\delta^2\leq1.5$	Yes

[a] Angular-correlation data was taken from Ref. 25 with $A_2=+0.121\pm0.060$ and $A_4=+0.08\pm0.10$. The 53-keV transition was assumed to be pure $M1$.
[b] From the present measurement of $\alpha_K(444)=0.012\pm0.002$ together with the theoretical α_K values of Ref. 18.

the Ru^{103} ground state would be inconsistent with the β decay ($\log ft=5.7$) to the $\frac{7}{2}^-$, 650-keV level ($\Delta I=2$, yes) of Rh^{103}. From shell model arguments, Mason *et al.* prefer an assignment of $\frac{5}{2}^+$ for this state. If this assignment is correct, then the strong β decay to the 536-keV level of Rh^{103} would indicate a $\frac{3}{2}^+$ assignment for this 536-keV level. With the presently available data, one cannot rule out the possibility of $\frac{7}{2}^-$ for the 536-keV level of Rh^{103} or the possibilities of $\frac{5}{2}^-$ or $\frac{7}{2}^-$ for the ground state of Ru^{103}.

It is still hard to understand certain features of the decay of Ru^{103} to levels in Rh^{103}. First of all, the large $M2$ admixture (60 to 80%) to the 557-keV $E1$ transition from the 650- to 93-keV level is rather unusual. Secondly, the absence of β decay to the $\frac{7}{2}^+$ 93-keV level is also difficult to explain.

In order to eliminate the remaining uncertainties in this decay scheme, several additional experiments would be desirable. For example, in the case of the strong 497-keV transition, the L_1/L_3 ratio is ~12 for pure $E2$ and ~40 for $E1+M2$. Therefore an L-subshell measurement at a momentum resolution of 0.05% or better can establish the multipolarity of this transition. This can decide the spin of the 536-keV level. A remeasurement of the Ru^{102}(d,p)Ru^{103} stripping reaction with modern experimental and computational techniques would be useful in establishing the spin and parity of the Ru^{103} ground state. Lastly, an independent measurement of the conversion coefficients for the transitions in Rh^{103} would serve as an additional check to the present multipolarity assignments.

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