Radioactive decay of 4.4-h ^{105}Ru to levels of ^{105}Rh†

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The energies, intensities and coincidences of the γ rays following the radioactive decay of 4.4-h ^{105}Ru to levels of ^{105}Rh have been determined. *85* γ rays have been fit into a level scheme between *25* excited states. Spin and parity assignments are deduced and discussed as are the results of earlier ^{104}Ru(^{3}He, d)^{105}Rh and ^{108}Pd(p, α)^{105}Rh reaction studies. The level structure of ^{105}Rh is compared with other odd-mass $41 \leq Z \leq 49$ nuclides and the presence of strong $E1$-$M1/E2$ competition discussed.

[RADIOACTIVITY ^{105}Ru; measured E_γ, I_γ, $\gamma\gamma$ coin; deduced logft. ^{105}Rh deduced levels, J, π. Ge(Li) detectors, enriched target.]

I. INTRODUCTION

Study of the structure and properties of the levels of $_{41}$Nb, $_{43}$Tc, $_{45}$Rh, $_{47}$Ag, and $_{49}$In offers an opportunity to observe the systematic effects arising from the filling of the $g_{9/2}$ orbitals. The level structure of all of these odd-mass nuclides is expected to be marked by low-lying $g_{9/2}$ and $p_{1/2}$ orbitals. Low-lying $\frac{7}{2}^+$ states characterized as "three-quasiparticle" or "intruder" levels are also well known[1] in Ag, Rh, and Tc nuclides. The recent studies[2,3] of the decay of ^{99,101}Mo to levels of ^{99,101}Tc which revealed the presence of very low-lying $\frac{5}{2}^+$ states and the recent studies[4,5] of ^{115,117}Cd decay to levels of ^{115,117}In which revealed low-lying $\frac{1}{2}^+$ and $\frac{3}{2}^+$ states have indicated the need for more careful studies of other Tc, Rh, and Ag nuclides.

Owing to the low Q values for β^- and electron capture (EC) decay to ^{103}Rh from ^{103}Ru and ^{103}Pd, respectively, ^{101}Rh and ^{105}Rh are the most easily studied of the Rh nuclei. The decay of ^{101}Pd to levels of ^{101}Rh has been studied carefully by Phelps and Sarantites[6] with high resolution Ge(Li) singles and coincidence techniques. On the other hand, the previous study[7] of ^{105}Rh decay to levels of ^{105}Rh by Schriber and Johns (hereinafter referred to as SJ) was carried out prior to the widespread use of large-volume high-resolution Ge(Li) detectors in $\gamma\gamma$ coincidence studies. More recently, Dittmer and Daehnick[8] (DD) investigated the levels of ^{105}Rh by utilizing the ^{104}Ru(^{3}He, d)^{105}Rh and ^{108}Pd(p, α)-^{105}Rh reactions. Because the low resolution results obtained by both of these studies have made interpretation of ^{105}Rh levels difficult, we have reinvestigated the decay of ^{105}Ru to levels of ^{105}Rh using large-volume (<50 cm^3) high-resolution (<1.9 keV) Ge(Li) detectors in both coincidence and singles experiments. Our results are in good agreement with those of SJ but raise some questions concerning the interpretation of the DD results.

II. EXPERIMENTAL PROCEDURES

Sources of 4.4-h ^{105}Ru were prepared by irradiating 10 mg samples of 96% enriched ^{104}Ru in the National Bureau of Standards (NBS) reactor for up to 10 min in fluxes up to $3\times10^{13}\ n\ \mathrm{cm}^{-2}\,\mathrm{sec}^{-1}$. The samples were boiled and washed twice with concentrated HCl to remove most of the impurities, although small amounts of Na and Br remained. The γ-ray spectrum shown in Figs. 1–4 was obtained by counting a source on a 50 cm^3 Ge(Li) detector whose full width at half-maximum (FWHM) values for 122- and 1332-keV γ rays were 750 and 1800 eV, respectively. Spectra of low-energy γ rays were taken with a Ge(Li) x-ray detector with FWHM of 175 eV for 5.9-keV x rays.

Coincidences were measured using two 55 cm^3 coaxial Ge(Li) detectors with FWHM values of 2.1 keV for 1332 keV γ rays in conjunction with a magnetic tape system for recording the addresses of coincident γ rays. The data were reduced using the University of Maryland Univac 1108 computer.[9]

Energy values were determined by counting ^{105}Ru sources simultaneously with a number of well-known γ-ray standards.[10-12] A sixth order polynomial calibration curve was fitted to the centroids of the standards and the energy values for the peak centroids determined from the calibration curve.

Relative intensity calibration was obtained using a NBS standard reference source[13] as well as several other isotopes with well-known intensity values. Absolute intensities were determined by assuming a negligible second-forbidden β intensity from $\frac{3}{2}^+$ ^{105}Ru to the $\frac{7}{2}^+$ ground state of ^{105}Rh. The experimental (SJ) α_K, α_L, and α_n values of SJ were used to compute the total transition intensity of the 129.6-keV level of 59. The 149.1-keV γ ray was assumed to be $M1$ and the 262.8-keV γ ray was assumed to be ~50% $E2$, and the 62.4-keV γ ray was taken to be ≳10% $E2$ for purposes of com-

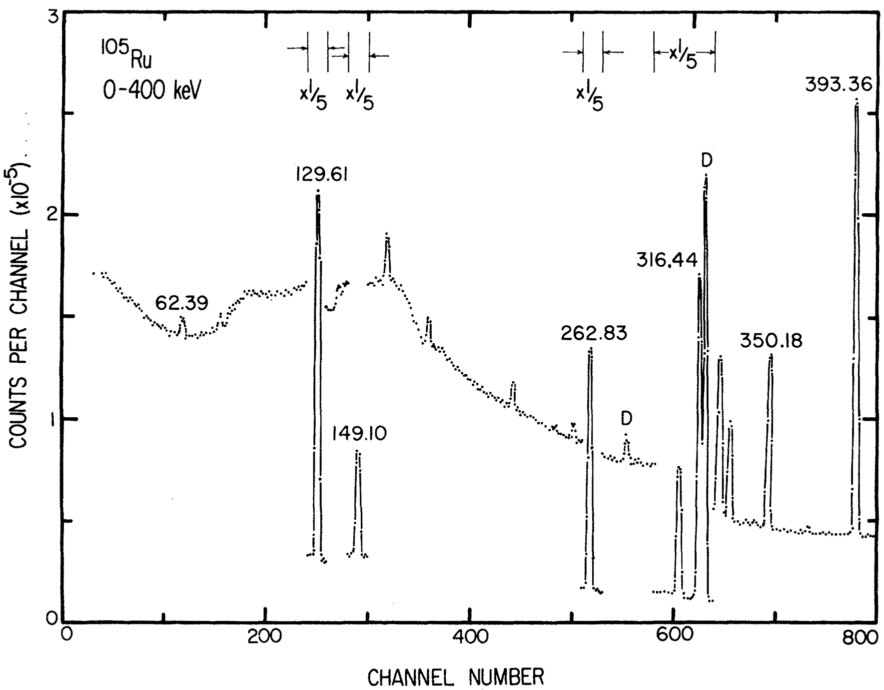

FIG. 1. γ-ray spectrum of ^{105}Ru decay, 0–400 keV. The peaks marked D arise from the daughter ^{105}Rh decay.

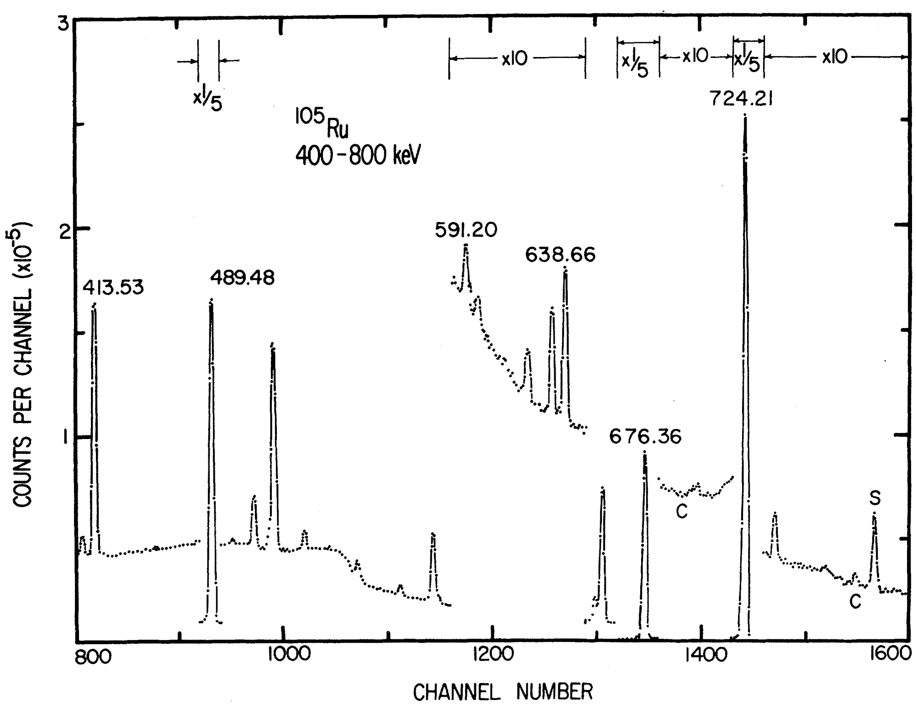

FIG. 2. γ-ray spectrum of ^{105}Ru decay, 400–800 keV. The peaks marked C arise from ^{82}Br contamination and the peak marked S is a sum peak.

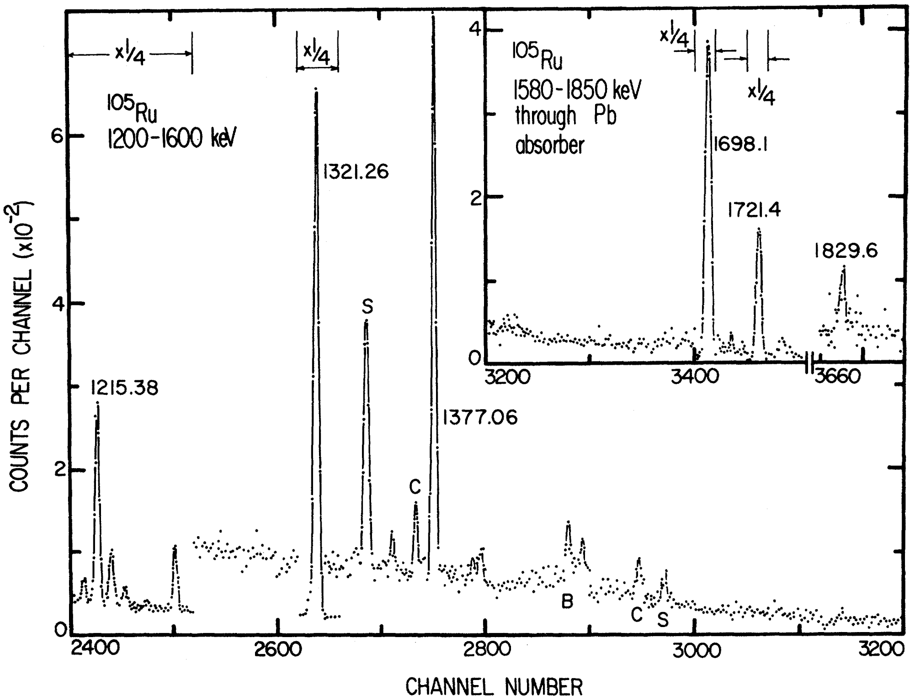

FIG. 3. γ-ray spectrum of ^{105}Ru decay, 1200–1900 keV. The peaks marked C arise from ^{82}Br and ^{24}Na contamination, those marked S are sum peaks, and the peak labeled B is from ^{40}K background.

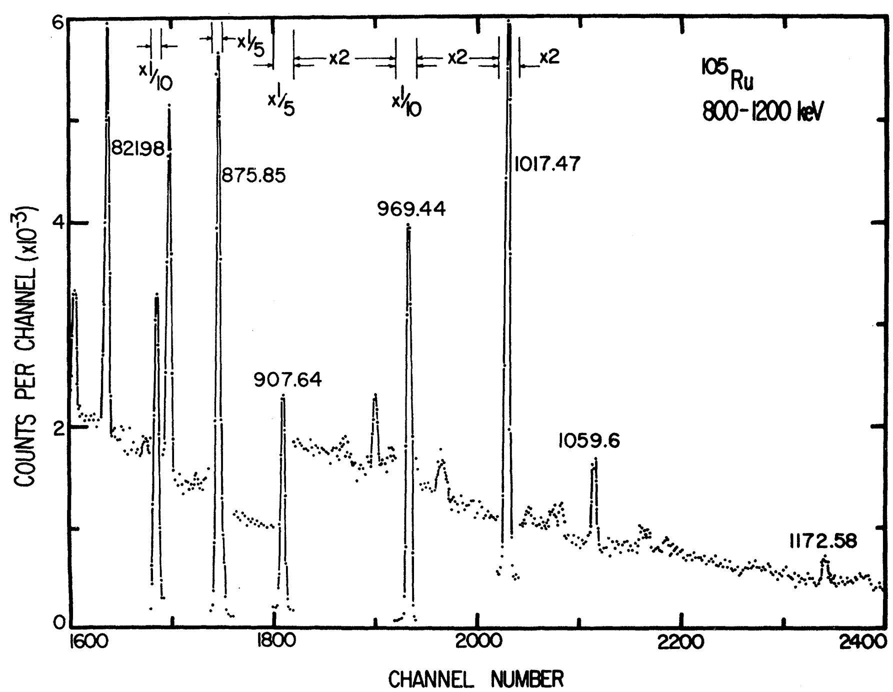

FIG. 4. γ-ray spectrum of ^{105}Ru decay to ^{105}Rh levels, 800–1200 keV.

puting the β-ray feedings and the logft values. Total ground state feeding of 210.2 intensity units were found and included 163 γ-ray units and 47.2 conversion electron intensity units.

III. THE DECAY SCHEME

With the exception of low-energy γ rays at 73.0, 75.3, 85.9, 87.9, 90.0, 92.0, 95.8, and 99.6 keV and γ rays proposed as parts of multiplets at 351, 656, and 876 keV, we observed all of the γ rays observed by SJ. We tabulate the γ rays observed and their positions in Table I. Our intensity values are also in good agreement with those of SJ.

Our decay scheme for ^{105}Ru is shown in Figs. 5 and 6. A dot at the lower end of a level has been used to indicate that that γ ray has been observed in coincidence with one or more γ rays feeding out of the level into which the γ ray feeds. A dot at the upper end of a γ ray is used to denote those γ rays used as gates for coincidence spectra.

TABLE I. γ-ray energies, intensities, and placements in 4.44-h ^{105}Ru decay. The numbers in parentheses represent the uncertainties in the last digit(s) of the numbers to which they are attached.

E_γ (keV)	I_γ	From	To	E_γ (keV)	I_γ	From	To
62.39 (10)	0.14 (2)	455	392	676.36 (8)	33.1 (10)	805	129
81.20 (10)	0.11 (2)	805	724	701.0 (2)	0.04 (1)	1486	785
129.61 (7)	12.0 (3)	129	g.s.	707 (1)	0.02 (1)	1345	638
139.33 (10)	0.10 (2)	638	499	724.21 (8)	100.0	724	g.s.
149.10 (7)	3.73 (30)	149	g.s.	738.27 (10)	0.16 (2)	1377	638
163.46 (10)	0.33 (4)	969	805	805.84 (15)	0.096 (20)	805	g.s.
183.60 (12)	0.21 (2)	969	785	820.0 (2) [a]	0.03 (1)	969	149
225.08 (12)	0.26 (2)	724	499	821.98 (12) [a]	0.45 (9)	1321	499
245.21 (15)	0.053 (10)	969	724	845.91 (12) [a]	1.33 (14)	1345	499
254.88 (12)	0.14 (2)	724	469	846.9 (2) [a]	0.06 (1)	1316	469
262.83 (10)	13.9 (3)	392	129	851.98 (10)	0.33 (4)	1321	469
286.3 (2)	0.06 (1)	785	499	875.85 (15) [a]	5.29 (20)	1345	469
306.66 (12)	0.17 (2)	805	500	878.2 (2)	1.0 (1)	1377	499
316.44 (15)	23.5 (8)	785	469	907.64 (10)	1.12 (12)	1377	469
326.14 (10)	2.25 (25)	455	129	952.78 (10)	0.032 (3)	1345	392
330.85 (10)	1.41 (16)	969	638	969.44 (10)	4.45 (15)	969	g.s.
339.4 (2)	0.03 (1)	469	129	977.9 (2)	0.004 (1)	1447	469
343.3 (2)	0.06 (1)	842	499	984.6 (2)	0.022 (4)	1377	392
349.96 (10) [a]	0.61 (3)	499	149	987.0 (2)	0.015 (3)	1486	499
350.18 (10) [a]	2.15 (25)	805	455	1017.47 (10)	0.68 (7)	1486	469
369.45 (12)	0.10 (2)	761	392	1059.6 (2)	0.057 (15)	1698	638
393.36 (10)	7.98 (10)	785	392	1082.7 (2)	0.017 (4)	1721	638
407.60 (15)	0.19 (2)	1377	969	1085.4 (2)	0.010 (3)	1809	124 [a]
413.53 (10)	4.76 (40)	805	392	1094	0.007 (2)	1486	392
469.37 (10) [a]	37.1 (11)	469	g.s.	1172.58 (20)	0.016 (4)	1321	149
470.12 (30) [a]	0.39 (5)	969	499	1209.0 (2)	0.013 (4)	1708	499
479.6 (2)	0.059 (2)	1447	969	1215.38 (10)	0.15 (2)	1345	129
489.48 (10)	1.16 (13)	638	149	1222.0 (2)	0.039 (5)	1721	499
499.26 (30) [a]	4.34 (50)	499	g.s.	1229.5 (2)	0.012 (3)	1698	469
500.1 (2) [a]	1.17 (16)	969	469	1238.8 (2)	0.004 (1)	1708	469
513.73 (10)	0.43 (10)	969	455	1251.89 (15)	0.041 (5)	1721	469
539.29 (10)	0.24 (2)	1345	805	1321.26 (10)	0.43 (5)	1321	g.s.
559.24 (10)	0.23 (2)	1345	785	1340	0.001	1809	469
572	0.02 (1)	1377	805	1357.2 (2)	0.005 (1)	1486	129
575.07 (12) [a]	1.80 (20)	724	149	1377.06 (11)	0.12 (2)	1377	g.s.
576.96 (30) [a]	0.04 (1)	969	392	1441.2 (2)	0.013 (4)	1441	g.s.
591.20 (15)	0.17 (2)	1377	785	1448.3 (2)	0.011 (3)	1448	g.s.
597.10 (15)	0.063 (15)	1321	724	1571	0.002 (1)	1721	149
621.04 (10)	0.15 (2)	1345	724	1698.1 (2)	0.16 (3)	1698	g.s.
632.34 (10)	0.32 (3)	761	129	1708.7 (2)	0.0010 (5)	1708	g.s.
635.5 (2)	0.03 (1)	1441	806	1721.36 (15)	0.07 (2)	1721	g.s.
638.66 (10)	0.47 (5)	638	g.s.	1765.4 (3)	0.0004 (3)	1765	g.s.
652.70 (10)	0.65 (7)	1377	724	1809	0.0005 (4)	1809	g.s.
656.21 (10)	4.35 (50)	785	129	1829.6 (3)	0.0016 (12)	1829	g.s.

[a] Energy and intensity values for these doublets were derived in part from coincidence data.

Levels proposed by SJ at 1215.2, 1269, and 1442 keV are not included as the 1215.4-keV γ ray has been placed elsewhere, no 876-keV γ ray was observed in coincidence with the 262-keV gate, and no 656-keV γ ray was observed in coincidence with the 656-keV gate. The level proposed at 1215.2 keV by SJ was based on a proposed 969.4-245.6-keV $\gamma\gamma$ coincidence cascade and the indication of a β group of 683 ± 36 keV in coincidence with the 1215.2-keV γ ray. We were unable to observe any evidence for a 245.6-keV γ ray in the spectrum gated on the 969.4-keV γ ray, instead observing the 245.6-keV γ ray in the spectrum gated on the 724.2-keV γ ray. No other γ rays were observed to feed in or out of a level at 1215.2 keV and only the 469- and 499-keV γ rays were observed in the coincidence gated on the 1200- to 1250-keV region. As these can result from the 1209.0-, 1229.5-, 1238.8-, and 1251.9-keV γ rays, and as the 1215.4-keV γ ray was not observed in any of the low-energy coincidence spectra, the 1215.4-keV γ ray must feed either the ground or isomeric state. Because of the good energy fit, the lack of other γ rays feeding into or out of a prospective level at 1215.2 keV, and the sizable uncertainties in the SJ $\beta\gamma$ coincidence data in which a NaI(Tl) γ-ray detector was utilized, we have shown the entire intensity of the 1215.4-keV γ ray associated with a transition from the 1345.2-keV level to the isomer. The possibility of a 1215.2-keV level cannot, however, be entirely eliminated.

A level was observed near 1016 keV by DD but our coincidence studies showed that the intensity of the 1017.1-keV γ ray can be accounted for by the transition between the levels at 1486.84 and 469.37 keV.

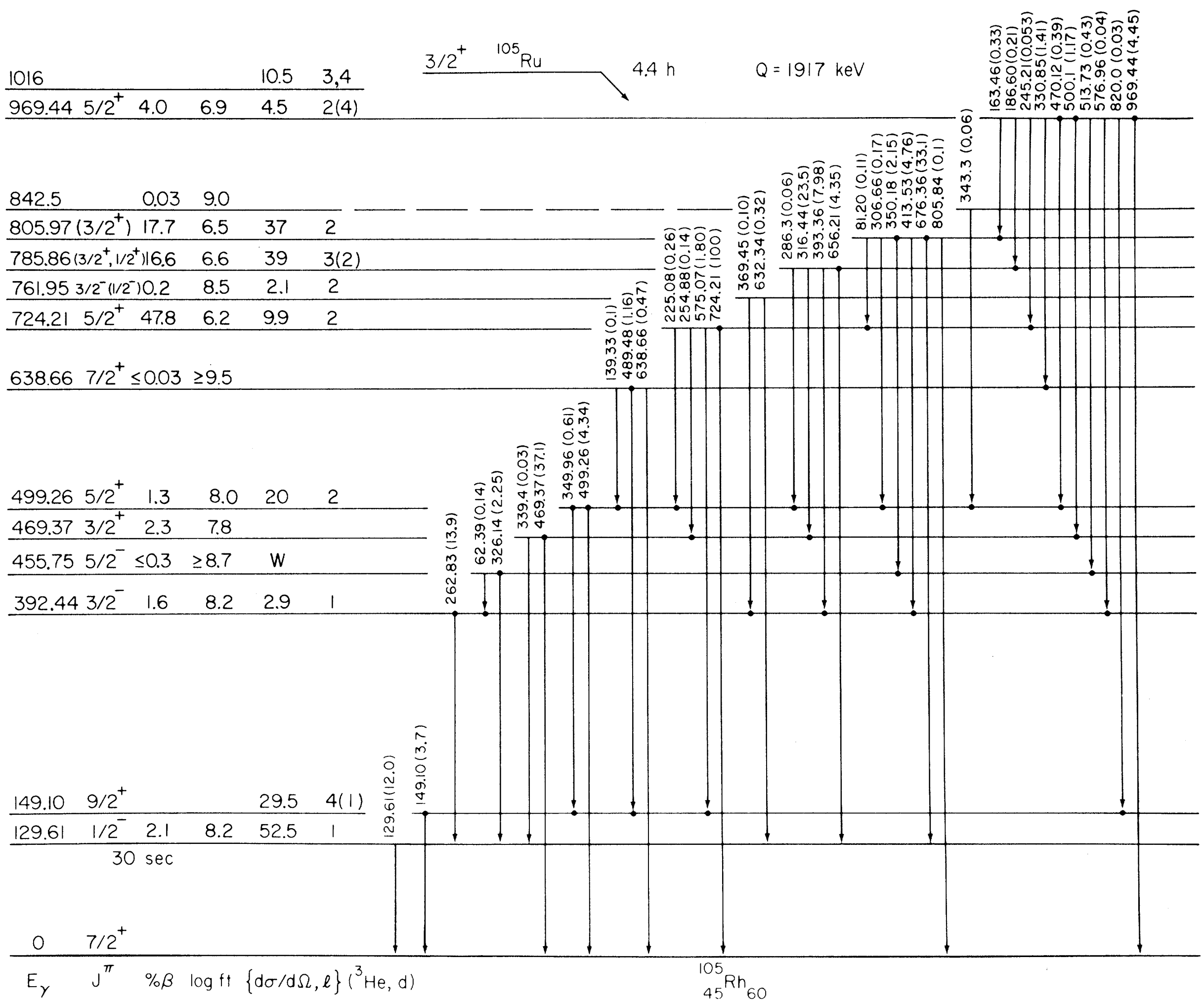

FIG. 5. Level scheme for ^{105}Ru decay to ^{105}Rh levels; lower levels. Listed also for each level are the % β feeding, the log*ft* value, the $d\sigma/d\Omega$ value, and the extracted l value for the levels observed in the (^{3}He, d) reaction.

A new level is proposed at 1708.7 keV on the basis of transitions to the ground state, 469-, and 499-keV levels. Two levels are tentatively proposed at 842.5 and 1316.3 keV on the basis of coincidence evidence. A weak γ ray at 846.9 keV was present in the 469 gate and the 469-keV γ ray was present along with the 499-, 350-, and 150-keV transitions in the 846-keV gate. The latter three arise from coincidences with the much larger 845.9-keV γ ray. A small peak at 343.3 keV was observed only in the 499-keV gate, indicating a possible level at 842.5 keV.

Two other weak γ rays are placed on the basis of the observation of levels by DD. These were the 1765.4- and 1829.6-keV γ rays which are shown feeding the ground state from levels at those energies. A level is placed at 1809 keV on the basis of weak transitions to the ground, 469-, and 724-keV states. A possible level exists near 1448 keV (not shown in Figs. 5 and 6) that deexcites by γ rays of 1448.3, 977.9, and 479.6 keV.

Some difficulty exists regarding the energies of the peaks observed by DD in the (p, α) reaction. The rather strong peak associated with the 392.4-keV level was indicated by DD as 401 keV. Three more peaks were observed and identified as 474-, 499-, and 524-keV peaks. Because of the 9-keV energy difference already noted, the question remains as to whether those peaks could be identified with the levels at 455.8, 469.4, and 499.3 keV observed in this study. Above 500 keV, only the peak in the (p, α) spectrum at 783 keV lies near any of the levels observed in the (^{3}He, d) spectrum or in the radioactive decay studies.

IV. SPIN AND PARITY ASSIGNMENTS

The recent measurements of Hrastnik *et al.*[14] showing a previously unresolved doublet for the

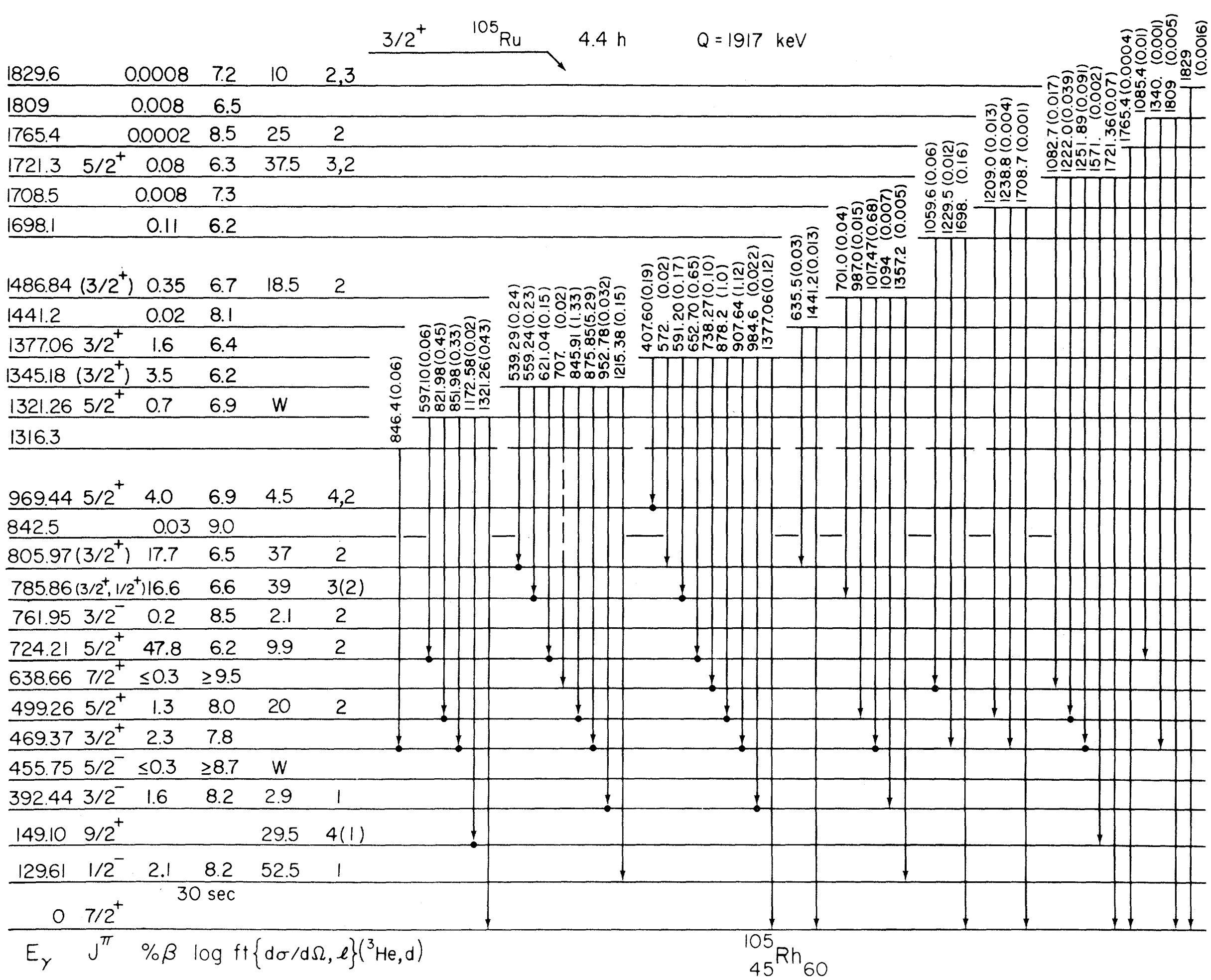

FIG. 6. Level scheme for ^{105}Ru decay to ^{105}Rh levels; upper levels. Listed also for each level are the % β feeding, the logft value, the $d\sigma/d\Omega$ value, and the extracted l value for the levels observed in the (^{3}He, d) reaction.

ground state of ^{105}Ru, with a $\frac{3}{2}^+$ assignment for the ground state, reduce the choices of spins and parities fed by allowed and first-forbidden β decay to $\frac{1}{2}^+$, $\frac{3}{2}^+$, $\frac{5}{2}^+$, and $\frac{1}{2}^-$, $\frac{3}{2}^-$, and $\frac{5}{2}^-$, respectively.

Spins and parities of $\frac{7}{2}^+$ and $\frac{1}{2}^-$ are the only assignments for the ground and 129.6-keV states consistent with the $E3$ character of the 129.6-keV transition, the $l=1$ stripping into the 129.6-keV state, and the allowed β decay of the ground state to the $\frac{5}{2}^+$ ground state of ^{105}Pd ($\frac{9}{2}^+$ and $\frac{3}{2}^-$ being the other possibility).

Shell model and systematic arguments suggest a $\frac{9}{2}^+$ assignment for the 149.1-keV state. DD were unable to obtain a consistent $l=4$ fit for this level in either the (^{3}He, d) or (p, α) reactions and suggested a doublet at this energy with the second component $p_{1/2}$ or $p_{3/2}$. We see no evidence for a second level near 150 keV and suggest that the peak from the ^{14}N(^{3}He, d)^{15}O reaction which underlies the 150 keV peak in the ^{104}Ru(^{3}He, d)^{105}Rh reaction and has strong $l=1$ forward peaking may account for this discrepancy.

The level at 392.4 keV is consistently found to be $\frac{3}{2}^-$ by all investigators.

The level at 455.8 keV decays to the $\frac{1}{2}^-$ and $\frac{3}{2}^-$ levels and is fed only very slightly, if at all, in β decay. In γ decay it is fed strongly only by the 806-keV level which also has strong branches to the $\frac{1}{2}^-$ and $\frac{3}{2}^-$ levels. Thus the parity of this level is quite likely negative. Among the negative parity choices, $\frac{1}{2}^-$ is ruled out by the significant branch from the $\frac{5}{2}^+$ state at 969.4 keV. SJ assigned a $\frac{3}{2}^-$ value on the basis of a K electron-conversion coefficient of 0.0107± 0.0017 for the 326.1-keV transition to the $\frac{1}{2}^-$ isomer. The conversion-coefficient data of SJ are, however, not sufficiently consistent to permit their utilization for definitive spin and parity assignments. We tabulate the SJ values in Table II along with the theoretical conversion coefficients for a number of ^{105}Rh γ-ray transitions

TABLE II. Conversion coefficients for ^{105}Rh γ rays.

E_γ (keV)	α_K (×10^3) (SJ)	Theoretical values (×10^3) (Ref. 15) $E1$	$M1$	$E2$
263	15.6 ±1.1	8.5	23	38
316	8.9 ±0.9	5.2	14	20
326	10.7 ±1.7	4.7	13	19
350	3.8 ±0.7	3.9	11	15
393	5.0 ±1.4	2.8	8.2	10
413	1.6 ±1.2	2.5	7.2	8.6
469	5.1 ±0.5	1.8	5.3	5.7
575	2.8 ±0.9	1.15	3.3	3.3
656	2.8 ±0.6	0.86	2.4	2.3
676	0.93±0.12	0.8	2.2	2.1
724	1.58±0.16	0.7	1.8	1.6

taken from the work of Hager and Seltzer[15] for $Z=45$. SJ deduce an α_K of 0.0089± 0.0009 for the 316-keV transition and assign the transition $E1$ multipolarity. As can be seen in Table II, such an α_K would in fact require a sizable $M2$ admixture. The 393.4-keV transition from that same level is reported to have an α_K of 0.005± 0.0014 and was assigned $M1$ and/or $E2$. Again, the value is much too low for $M1$ and too high for an $E1$ transition. It would be convenient to argue that the SJ α_K values are systematically high or low and that the 316.4- and 393.4-keV transitions are both $E1$ transitions or both $M1/E2$ transitions and that other SJ α_K values should be raised or lowered accordingly and then reinterpreted. This is not possible, as the 316.4- and 393.4- keV γ rays decay from the same level at 785.9 keV to levels at 392.4 and 469.4 keV, respectively, whose spins and parities are $\frac{3}{2}^-$ and $\frac{3}{2}^+$, respectively. Thus, the 316.4- and 393.4-keV transitions are not the same multipolarity; one is in fact $E1$ with a measured value too high and the other $M1/E2$ with a measured value too low. We might note a further inconsistency for the 350-keV doublet. 22% of that peak is placed from the $\frac{5}{2}^+$ 499.3-keV level to the $\frac{9}{2}^+$ 149.6-keV level and is hence pure $E2$. The α_K for a pure $E2$ transition is 0.015. Thus, the contribution to the measured α_K from this fraction alone would be 0.0031, yet the total measured α_K for the peak is reported by SJ as 0.0038± 0.0007, leaving only a 0.0007 contribution from the other 78% of the peak. We cite these above values to suggest that the SJ α_K values are erratically in error, rather than systematically high or low.

Returning to the question of spin for the 455.8-keV level, we favor a $\frac{5}{2}^-$ assignment on the basis of the presence of a highly analogous level in ^{103}Rh which decays[16] to the lower-lying $\frac{1}{2}^-$ and $\frac{3}{2}^-$ levels in a ratio very similar to that of the 455.8-keV level. A comparable $\frac{5}{2}^-$ level exists[17] in isotonic ^{107}Ag at 422 keV. Furthermore, if our juxtaposition of levels for the (p, α) data are valid, the peak assigned by DD to 474 keV belongs to this level. They suggested a $g_{9/2}$ assignment for this level, an assignment out of the question for both the 455.8- and 469.4-keV levels. Furthermore, the calculated DWBA fit shown by DD does not fit the observed peak near 85°. It is possible to note, however, that the calculated $l=3$ angular distribution shown by DD for the 0.817- and 0.524-MeV levels could also fit the curve shown for the level at 0.474 MeV, including the peak near 85°. What cannot be ruled out, of course, is a $\frac{9}{2}^+$ level at ~460 KeV that would not be populated in our work.

The level at 469.4 keV is not clearly observed in either the (^{3}He, d) or (p, α) reactions. It decays strongly to the $\frac{7}{2}^+$ ground state and has a very weak branch to the $\frac{1}{2}^-$ isomer. Spins and parities of $\frac{5}{2}^-$ or $\frac{3}{2}^+$ are possible with the latter strongly favored because of the large number of γ-ray branches from higher lying levels with intensities quite similar to the branches to the $\frac{5}{2}^+$ 499.3-keV level. A $\frac{5}{2}^+$ spin and parity for the 469.4-keV level has been proposed[18] on the basis of angular correlation data between the 469.9- and 316.4-keV γ rays. For this assignment, however, a pure dipole character ($E1$) was assumed for the 316.4-keV γ ray. As that $E1$ assignment is in some doubt, and as the $A2$ value of 0.081 ± 0.008 for the 469.4-keV transition is within 3σ of the value for a $\frac{3}{2}^+$ assignment (still assuming $E1$) and quite satisfactory for the cases where the 316.4-keV γ ray is $M1$-$E2$, our assignment is in only a slight conflict with the angular correlation data.

The level at 499.3 keV is populated in an $l=2$ transition in the (^{3}He, d) reaction indicating $\frac{3}{2}^+$ or $\frac{5}{2}^+$ spin and parity. As the level decays to the $\frac{9}{2}^+$ state at 149 keV, its spin and parity are restricted to $\frac{5}{2}^+$.

The level at 638.7 keV feeds levels with spins and parities of $\frac{5}{2}^+$, $\frac{7}{2}^+$, and $\frac{9}{2}^+$, is not fed in β decay, and is not observed in the (p, α) or (^{3}He, d) studies. These characteristics suggest $\frac{7}{2}^+$ or $\frac{9}{2}^+$ spins and parities. A weak γ-ray branch from the $\frac{3}{2}^+$ level at 1377.06 keV dictates a $\frac{7}{2}^+$ assignment.

The 724.2-keV level is readily assigned $\frac{5}{2}^+$ spin and parity as the level is strongly fed in β decay, feeds the $\frac{9}{2}^+$ level at 149.1 keV, and is seen in an $l=2$ transition in the (^{3}He, d) reaction.

Assignments consistent with all of the data for the three levels at 761.9, 785.9, and 806.0 keV are not possible. Consider the level at 761.9 keV; it is weakly fed in β decay, suggesting negative parity and, as it feeds only the $\frac{1}{2}^-$ and $\frac{3}{2}^-$ levels, would appear to be a clearcut $\frac{1}{2}^-$ or $\frac{3}{2}^-$ level. However, the same level was observed with an $l=2$ value in the (^{3}He, d) reaction. The feeding of the $\frac{1}{2}^-$ state completely rules $\frac{5}{2}^+$ out. Surely this would be one of the more unusual $\frac{3}{2}^+$ levels known if it completely failed to feed any of the several $\frac{3}{2}^+$, $\frac{5}{2}^+$, and $\frac{7}{2}^+$ states below it. We favor the $\frac{3}{2}^-$ assignment, but are at a loss to understand the $l=2$ value from the (^{3}He, d) reaction.

The levels at 785.9 and 806.0 keV are alike in many respects. They are fed equally and strongly in β decay and populated with almost equal intensity in the ^{104}Ru(^{3}He, d)^{105}Rh reaction. They are also fed almost equally by the γ-ray deexcitation of the 969.4-keV $\frac{5}{2}^+$ level and the 1345.18-keV $\frac{3}{2}^+$ level. They also both show weak γ branches to the $\frac{5}{2}^+$ level at 499.3 keV. These data would indicate positive parity for the above levels, although clear l values from the (^{3}He, d) were not obtained by DD for either of these transitions.

Arguments for negative parity may be derived from the strong γ-ray branches from both levels to the $\frac{1}{2}^-$ and $\frac{3}{2}^-$ levels at 129.6 and 392.4 keV. Arguments for different parity for the two levels may be derived from the α_K values of SJ which indicate $E1$ multipolarity for the 676-keV transition and $M1$ or $E2$ multipolarity for the 656-keV transition. A $\frac{3}{2}^+$ assignment for the 806-keV state is consistent with most of the above data. The data for the 785.9-keV level do not permit an assignment consistent with all of the data. The (p, α) data indicate a $\frac{3}{2}^-$ assignment for the level, an assignment consistent with the listed (though highly erratic) α_K values of SJ. The (^{3}He, d) data indicated a higher l value of 3 or possibly 2, suggesting spins and parities of $\frac{3}{2}^+$, $\frac{5}{2}^+$, or $\frac{7}{2}^-$. The logft value is much too low for a $\frac{7}{2}^-$ assignment and the γ branch to the $\frac{1}{2}^-$ isomer eliminates the $\frac{5}{2}^+$ possibility. The best assignment from our data alone would be $\frac{1}{2}^+$; however, we would have expected the $l=0$ angular distribution to have been quite obvious in the work of DD. We have listed a tentative $\frac{3}{2}^+$ assignment which is partially supported by the possible $l=2$ value from the (^{3}He, d) reaction study. Such an assignment is in conflict with the $l=1$ value from the (p, α) study and the erratic, but consistent, α_K values of SJ.

The 969.4-keV level is almost assuredly a $\frac{5}{2}^+$ level as it feeds $\frac{3}{2}^+$, $\frac{5}{2}^+$, $\frac{7}{2}^+$, $\frac{9}{2}^+$, $\frac{3}{2}^-$, and $\frac{5}{2}^-$ levels. DD were unable to obtain a clear $l=2$ fit for the (^{3}He, d) population of this level and suggested a doublet with the second level $l=4$. We would be unlikely to observe population of the $l=4$ level in β decay and our coincidence data indicate both the 500.1- and 513.7-keV γ rays in coincidence with the 407.6-keV γ ray.

The 1321.3 keV level feeds the $\frac{9}{2}^+$ level at 149.1 keV as well as $\frac{5}{2}^+$ and $\frac{7}{2}^+$ states and must be $\frac{5}{2}^+$ or $\frac{7}{2}^+$ itself. Of these two choices, only $\frac{5}{2}^+$ can be strongly β-fed from a $\frac{3}{2}^+$ parent.

The 1345.2-keV level feeds low-spin levels of both parities, positive parity much more strongly than negative parity, and is assigned $\frac{3}{2}^+$. Were it not for the weak 707-keV γ ray feeding the $\frac{7}{2}^+$ level at 638.7 keV, $\frac{1}{2}^+$ would be an attractive choice for this level. The 1377.1-keV level feeds $\frac{7}{2}^+$, $\frac{5}{2}^+$, $\frac{3}{2}^+$, and $\frac{3}{2}^-$ levels and is $\frac{3}{2}^+$ or $\frac{5}{2}^+$, with $\frac{3}{2}^+$ favored owing to the absence of any branch to the $\frac{9}{2}^+$ state at 149.1 keV.

The 1486.8-keV level is strongly populated by an $l=2$ or $l=3$ transition in the (^{3}He, d) reaction and feeds the $\frac{1}{2}^-$ isomer by a weak γ ray and the $\frac{3}{2}^+$ level at 469.4 keV by a strong transition. Of the possible spin-parity assignments consistent with $l=2$ or $l=3$, $\frac{3}{2}^+$, $\frac{5}{2}^+$, $\frac{5}{2}^-$, or $\frac{7}{2}^-$, the $\frac{7}{2}^-$ possibility is eliminated by the logft value of 6.8 which is well below the range for first forbidden unique transitions. The $\frac{5}{2}^+$ possibility is eliminated by the presence of the γ branch to the $\frac{1}{2}^-$ isomer as this branch is much too strong to be an $M2$ transition unless the 1017-keV γ ray is a pure $E2$ transition with a sizable hindrance. Of the remaining choices, $\frac{3}{2}^+$ or $\frac{5}{2}^-$, we favor the $\frac{3}{2}^+$ on the basis of the strong γ-ray branch to the $\frac{3}{2}^+$ level at 469.4 keV and because DD favor the $l=2$ assignment for the transition observed to this state in the (^{3}He, d) reaction. For $\frac{5}{2}^-$ to be correct would require the 1017.4-keV γ ray to be a virtually unhindered $E1$ with the $M1$ and $E2$ transitions to the $\frac{1}{2}^-$ isomer and $\frac{3}{2}^-$ 392.4-keV level strongly hindered. In view of the observed sizable spectroscopic factors (0.16 for the 392.4-keV level and 0.43 for the $l=3$ assignment for the 1486.8-keV level) such a high $M1$ hindrance is quite unlikely.

V. DISCUSSION

The low-lying level structure of ^{105}Rh is compared with $^{93}_{41}$Nb$_{52}$,[19] $^{99}_{43}$Tc$_{56}$,[2] $^{101}_{43}$Tc$_{58}$,[3] $^{101}_{45}$Rh$_{56}$,[6] $^{103}_{45}$Rh$_{58}$, $^{107}_{47}$Ag$_{60}$,[17] $^{109}_{47}$Ag$_{62}$,[18] ^{111}Ag,[20] and $^{115}_{49}$In$_{66}$[5] in Figs. 7 and 8. The levels of ^{93}Nb represent the ideal, simple, particle-plus-phonon structure that would be expected of a single particle beyond a closed shell. The $\frac{3}{2}^-$ and $\frac{5}{2}^-$ states can be viewed as the $\frac{1}{2}^-$ single particle coupled to the 2^+ first excited state of $^{92}_{40}$Zr$_{52}$ and slightly lowered by the presence of single particle $2p_{3/2}$ and $1f_{5/2}$ occupied levels lying at higher energies. The $\frac{5}{2}^+$, $\frac{7}{2}^+$, $\frac{9}{2}^+$, $\frac{11}{2}^+$, and $\frac{13}{2}^+$ levels may be viewed as the pentuplet resulting from the coupling of the $1g_{9/2}$ ground state with the 2^+ core. These same features are expected to be observed for the remaining nuclides with odd Z between 41 and 49. As can be seen in the structure of one-hole ^{115}In, comparable levels are present along with the anomalous $\frac{1}{2}^+$, $\frac{3}{2}^+$, $\frac{5}{2}^+$, and $\frac{7}{2}^+$ states.

The $\frac{3}{2}^-$ and $\frac{5}{2}^-$ states indicated above are, in fact, observed for nearly all of the other nuclides shown in Figs. 7 and 8. For many nuclides in which the second 2^+ state of the even-even core falls at a low enough energy, a second pair of $\frac{3}{2}^-$ and $\frac{5}{2}^-$ levels are observed along with $\frac{7}{2}^-$ and $\frac{9}{2}^-$ levels that arise

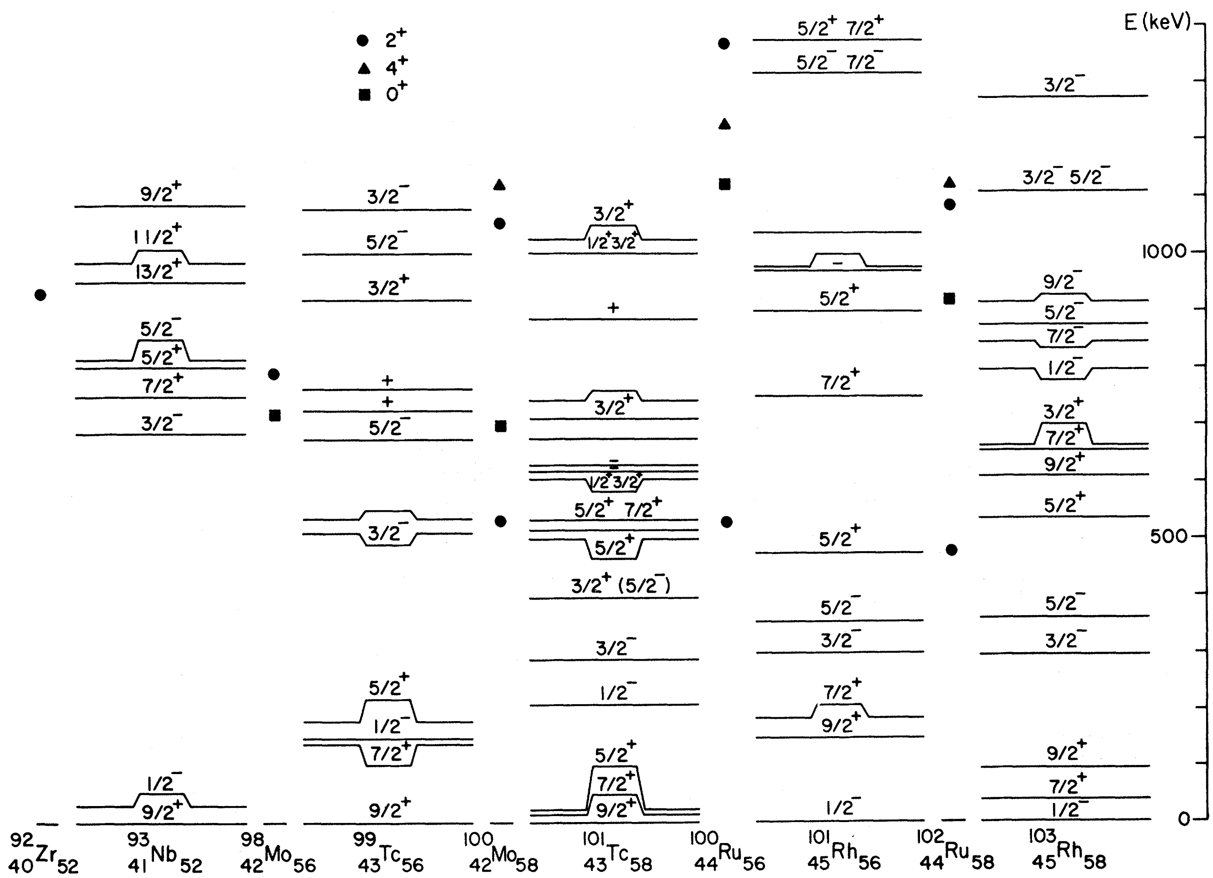

FIG. 7. Systematics of $41 \leq Z \leq 45$ levels. The observed levels in the adjacent even-even nucleus are denoted by 0^+ (■), 2^+ (●), and 4^+ (▲).

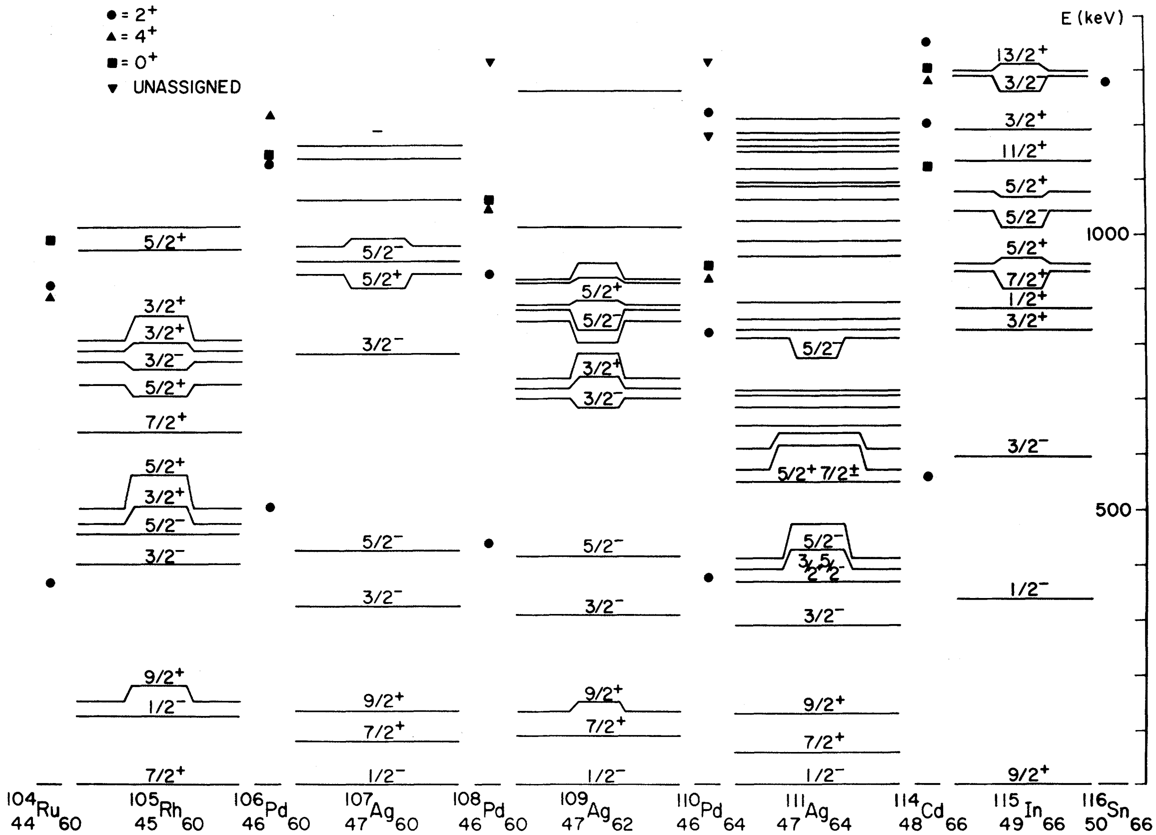

FIG. 8. Systematics of $45 \leq Z \leq 49$ levels. The observed levels in the adjacent even-even nucleus are denoted by 0^+ (■), 2^+ (●), and 4^+ (▲).

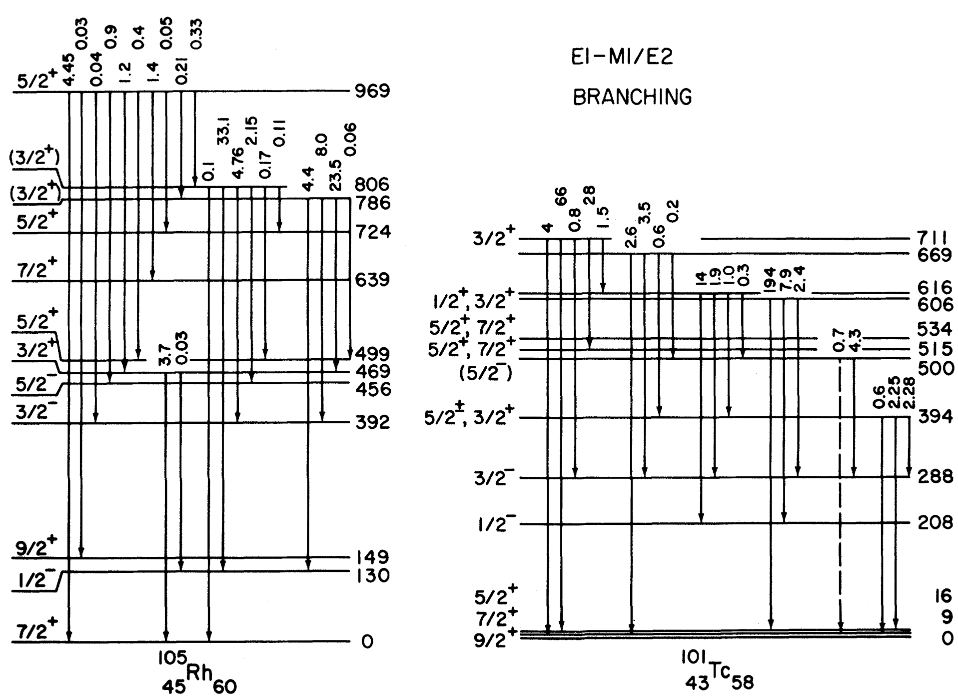

FIG. 9. $E1$-$M1/E2$ branching from selected ^{101}Tc and ^{105}Rh levels.

from the coupling of the $p_{1/2}$ isomer to the 4^+ state of the even-even core.

The structure of the positive parity states of Tc, Rh, and Ag nuclides is dominated by the presence of the three-quasiparticle intruder states and by the general softness[21] of the nuclear core as indicated by the low energy of the first 2^+ state. As a consequence of these features, a high level density is observed at low energies in ^{101}Tc and ^{111}Ag. With a $\frac{3}{2}^+$ ^{105}Ru β decay parent, our data should be most comparable to that for ^{101}Tc populated by the β decay of $\frac{1}{2}^+$ ^{101}Mo. Clearly no $\frac{5}{2}^+$ three-quasiparticle level is present at lowered energy comparable with the 15-keV level in ^{101}Tc. It can be concluded that the depressed $\frac{5}{2}^+$ state observed in the Tc nuclides is a phenomenon peculiar to the Tc nuclides with no counterpart in the Rh nuclides. On the other hand, the density of $\frac{5}{2}^+$ states is seen to be significant as three are observed below 1 MeV.

A feature that the Tc, Rh, and Ag nuclides do have in common is the relatively strong $E1$ transition strength between levels below 1 MeV. These branchings are shown in Figs. 9 and 10 for selected levels in ^{101}Tc, ^{105}Rh, ^{107}Ag, and ^{109}Ag. The sizable (^{3}He, d) strengths to the levels in ^{105}Rh at 786, 806, and 969 keV combined with the sizable $E1$ branches from these levels to the lower-lying $\frac{3}{2}^-$ levels are consistent with an interpretation of sizable single particle contributions to the character of these levels. Similar $l=2$ strength[22] is observed in the ^{106}Pd(^{3}He, d)^{107}Ag for the 1222- and 922-keV $\frac{5}{2}^+$ levels in ^{107}Ag. For the ^{101}Tc no (^{3}He, d) data are available, but studies[23] of the (^{3}He, d) reaction into ^{93,95,97}Tc reveal a clear lowering and splitting of $l=2$ strength from a single strongly populated level at 3.34 MeV in ^{93}Tc to levels as low as 0.785 MeV in ^{97}Tc. Taken as a whole, these data indicate the presence of considerable strength from the single proton levels above the $Z=50$ closed shell. Whether these are one particle 2, 4, 6, and 8 hole states or whether they are Nilsson levels lowered as a consequence of possible deformations remains to be determined. The recent studies[24] indicating possible particle-rotation coupling in odd-N ^{101}Pd suggest the latter possibility may prove attractive.

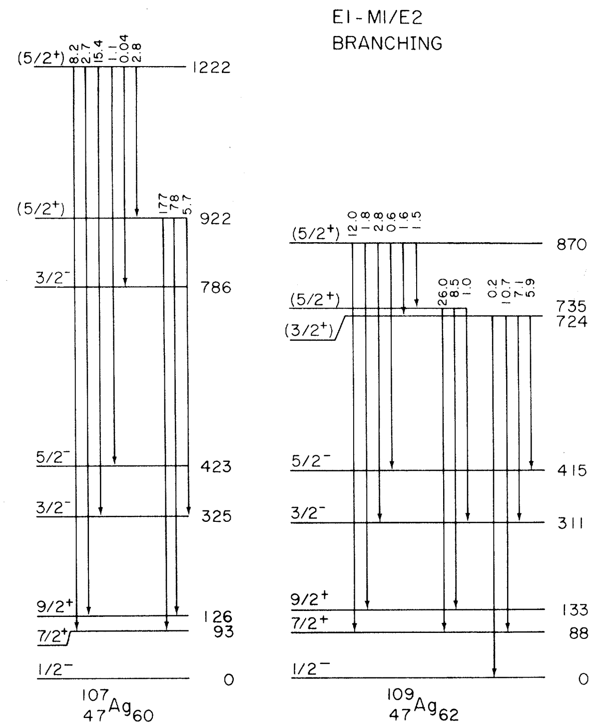

FIG. 10. $E1$-$M1/E2$ branching from selected ^{107}Ag and ^{109}Ag levels.

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