Gamma-Decay Scheme of the 4.4-min Rh^{104m} Isomer

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The gamma-decay scheme of the 4.4-min Rh^{104m} isomer has been investigated using scintillation detectors and coincidence circuitry. In 96.2% of all decays, the principal decay mode from the 129-keV Rh^{104m} isomeric level has been found to be a 77-keV transition with $E3$ multipolarity to a 52-keV level, from which decay occurs to the ground state (with a 1+ spin and parity) by an $E1$ transition. A secondary decay mode (3.8% branching ratio) has been found to be from the 129-keV level to a 96-keV level by a highly converted $M3$ transition, from which decay occurs to the ground state by an $M1$ transition. An upper limit of 0.1% could be set on the possibility of a 44-keV transition from the 96-keV level to the 52-keV level. The K internal conversion coefficients of the 52- and the 77-keV transitions have been determined as $0.89_{-0.09}{}^{+0.07}$ and 17.9 ± 2.0, respectively, while an approximate $(L+M+\cdots)/K$ conversion ratio of 3.7 was obtained for the 33-keV transition. Spin and parity assignments of 5+, 2+, and 2− were made to the 129-, 96-, and 52-keV levels, respectively. The Rh^{104} ground state can be assigned as having a $[(g_{9/2})^5]_{7/2}(d_{5/2})^n$ shell-model configuration and, while the 129- and 96-keV levels can also probably be assigned this configuration, there is a possibility that either one, or both, of these states has a $(g_{9/2})^5(d_{5/2})^n$ configuration instead. The only reasonable configuration assignment for the 52-keV level is as a $(p_{1/2})(d_{5/2})^n$ state.

INTRODUCTION

PREVIOUS investigators[1–10] have shown that when stable Rh^{103} is irradiated with thermal neutrons, a 4.4-min isomer of Rh^{104} is produced which decays predominantly by gamma emission to the ground state of Rh^{104}. Investigations of the isomeric Rh^{104m} decay are complicated by the fact that Rh^{104} is itself unstable, decaying by β^- emission with a 44-sec half-life[11,12] to stable Pd^{104}. This Rh^{104} decay has been found to occur primarily to the ground state of Pd^{104} by a 2.5-MeV beta transition. Weak 560-keV and 1.2-MeV gamma radiations were also observed to be associated with the Rh^{104} decay.[13–16] These gamma rays occur in the decay from Pd^{104} levels at 1.80 MeV and 556 keV, which are fed in the Rh^{104} decay by beta transitions with energies and intensities of 700 keV (0.08%) and 1.9 MeV (1.4%).[14] Bunker *et al.*[14] observed that the 4.4-min Rh^{104m} isomer was also beta unstable and that 0.1% of its decays were by β^- emission to Pd^{104}. Gamma rays having energies 556 keV, 740 keV, 780 keV, and 1.53 MeV were found to be associated with this decay mode. Girgis and van Lieshout[15] found, in addition, 1.25- and 1.8-MeV gamma rays which could be associated with the beta decay of either the isomeric or the ground-state Rh^{104} decay. A consistent Pd^{104} energy level scheme which incorporates all of these gamma transitions, is given by Girgis and van Lieshout.[15,16]

It was found in early investigations[3,8,9] that gamma rays having energies of 20 and 51 keV were associated with the Rh^{104m} isomeric decay. The 20-keV gamma peak was interpreted as rhodium K x rays produced in the K internal conversion of transitions from a 4.4-min isomeric state at 51 keV. On this basis Germagnoli *et al.*[9] obtained the K internal conversion coefficient of the 51-keV transition as 1.9. Jordan *et al.*,[10] however, using a 180° constant magnetic field photographic spectrometer, found evidence for the existence of a 77.2-keV gamma transition associated with the Rh^{104m} isomeric decay. The K/L conversion ratios of the 51.1- and 77.2-keV transitions were determined to be ≥ 5 and approximately 0.6, respectively. Also, from coincidence studies, it was determined that the 51-keV gamma rays were in coincidence with rhodium K x rays which were interpreted as coming from the strongly converted 77-keV transition. On the basis of these data, Jordan *et al.*[10] proposed the decay scheme shown in Fig. 1 for Rh^{104m}. The 1+ spin assignment on the ground state of Rh^{104} was made since Rh^{104} decays predominantly to the ground state of Pd^{104} with a logft value of approximately 4.7. The Nuclear Data Group,[17] by comparing the re-

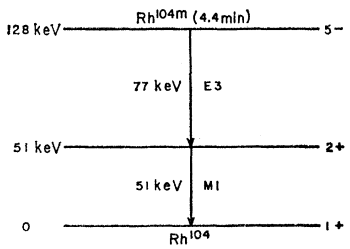

FIG. 1. The Rh^{104m} decay scheme proposed by Jordan, Cork, and Burson (reference 10).

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[16] R. K. Girgis and R. van Lieshout, Nucl. Phys. **13**, 509 (1959).
[17] *Nuclear Data Sheets* (Printing and Publishing Office, National Academy of Sciences–National Research Council, Washington 25, D. C.).

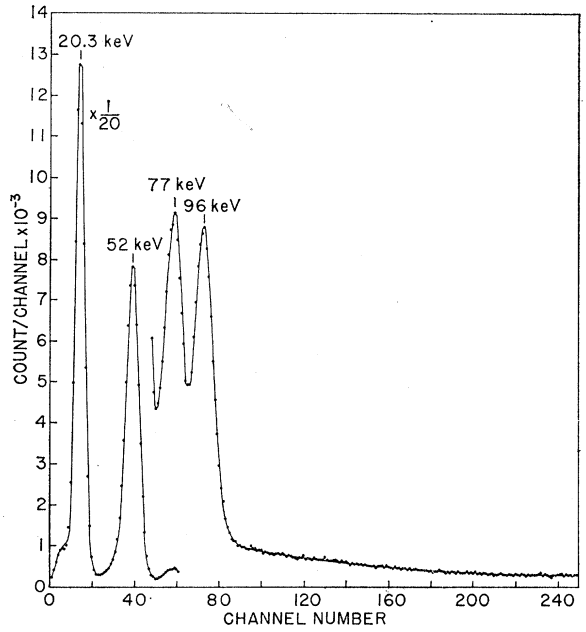

FIG. 2. Singles gamma-ray spectrum of the 4.4-min isomer of Rh^{104m} obtained with a $1\frac{1}{2}$ in. $\times$ 1 in. NaI(Tl) scintillation spectrometer.

sults of Germagoli[9] and Jordan *et al.*,[10] suggested that the 51-keV transition was, in fact, an $E1$ transition and that the spins and parity assignments to the 51- and 128-keV levels of Rh^{104} were 2− and 5+, respectively. In this respect, it is interesting to note that recently Du Toit and Bollinger[18] measured the half-life of this 51-keV transition from the neutron capture gamma-ray spectrum of rhodium as 2.6 ± 0.2 nsec. Such a transition lifetime could correspond to either a highly retarded (by a factor of approximately 3×10^3) $E1$ transition or a retarded (by a factor of approximately 50) $M1$ transition. They pointed out, however, that such a retardation is not abnormally slow for an $E1$ transition.

In addition to the 51- and 77-keV gamma rays, mentioned above, a weak 97-keV gamma ray was also observed by Miller[19] which, from half-life studies, appeared to be associated with either the isomeric Rh^{104m} or the Rh^{104} decay. This 97-keV transition was also observed by Stone and Oestreich[20] who found, by observing its intensity as a function of time within 30 sec of production, that it belonged to the Rh^{104m} decay and not to the Rh^{104} decay. This study of the isomeric Rh^{104m} decay scheme was, therefore, undertaken in order to help remove these remaining inconsistencies.

EXPERIMENTAL

A. Gamma-Ray Scintillation Spectra

Sources of Rh^{104m} were produced for these experiments by irradiating samples of spectroscopically pure rhodium sponge in the Armour Research Reactor. Samples could be irradiated close to the reactor core for a predetermined time and removed rapidly by use of the pneumatic "rabbit" facility of this reactor. Irradiation times and sample masses were dependent on the type of experiment to be performed.

The gamma-ray spectra were studied principally with a scintillation detector consisting of a $1\frac{1}{2}$ in.$\times$1 in. NaI(Tl) crystal, with a 0.001-in. aluminum foil gamma-ray entrance window, integrally mounted on an RCA 6342A photomultiplier tube. Pulse-height analysis was accomplished with a 512-channel pulse-height analyzer.

A typical Rh^{104m} spectrum, obtained using a source to crystal distance of 4 in., and with a $\frac{1}{2}$-in.-thick Lucite sheet between the source and crystal to stop the 2.5-MeV betas, is shown in Fig. 2. To obtain this spectrum, a 10-mg sample of rhodium sponge compressed in a uniform layer between high-purity aluminum foil (the total mass of aluminum was 38 mg) into a $\frac{5}{8}$-in.-diam disk was irradiated in the reactor for 3 min and counted for an 8-min lifetime approximately 35 min after removal from the reactor. At this time, the 2.3-min Al^{28} activity produced a negligible contamination to the Rh^{104m} spectrum. In the spectrum shown in Fig. 2 a peak at 96 keV is clearly visible together with the well-known lines at 52 and 77 keV and the rhodium K x-ray peak. To obtain accurate intensity ratios for these lines, a series of such Rh^{104m} spectra were taken using source to crystal distances of both 4 in. and 8 in., together with no Lucite beta absorber, a $\frac{1}{4}$-in. Lucite absorber, and the $\frac{1}{2}$-in. Lucite absorber. To facilitate such intensity measurements, gamma transmission curves were obtained for each of these Lucite absorbers using standard long-lived isotopes (under conditions of identical geometry to those used in the Rh^{104m} spectral measurements) with lines in this low-energy region. After correcting the peak intensities observed in these Rh^{104m} spectra for the iodine escape peaks, random coincidence summing and real coincidence summing effects (particularly by the rhodium K x rays and the 52-keV gamma rays), gamma-ray transmissions, gamma-ray self-absorption in the rhodium, detection efficiencies, etc., it was determined that the average relative intensities of the rhodium K x rays, the 52-keV gamma rays, the 77-keV gamma rays, and the 96-keV gamma rays were, 1.66_4, 1.000, $5.3_7\times10^{-2}$, and $5.5_6\times10^{-2}$, respectively.

To confirm that the 96-keV line observed in Fig. 2 really does belong to the 4.4-min Rh^{104m} decay, experiments were undertaken to determine the relative lifetime of the 96-keV line with respect to the other three lines observed. The first series of such lifetime measurements was accomplished under the same conditions as were used to obtain the spectrum shown in Fig. 2, with the exception that the spectra were obtained for a 1-min elapsed time and were stored in groups of 128 channels in the pulse-height analyzer. Six such spectra were obtained in the time interval between 35 and 50 min (i.e., over more than three Rh^{104m} lifetimes) after

[18] S. J. Du Toit and L. M. Bollinger, Phys. Rev. **123**, 629 (1961).
[19] C. E. Miller, Oak Ridge National Laboratory Report ORNL-2715, 1959 (unpublished) and (private communication).
[20] C. A. Stone and D. Oestreich (private communication).

the source was produced. In these spectra, the relative intensity of the 96-keV peak with respect to the other three peaks was found to be constant. It can, therefore, be concluded that the 96-keV line is associated with the Rh^{104m}–Rh^{104} equilibrium decay since none of the other activities produced in the reactor, i.e., by (n,p), (n,pn), and (n,α) reactions with rhodium, or neutron capture by the known impurities in the rhodium sample, have a 4.4-min half-life. To determine whether the 96-keV gamma radiation was associated with the 4.4-min isomeric decay of Rh^{104m} or whether it was produced in the 44-sec β^- decay of the ground-state Rh^{104}, use was made of the fact that the neutron capture cross section for the production of the Rh^{104m} isomer is 12 b whereas the Rh^{104} ground state is produced with a 138-b capture cross section. Consequently, if the 96-keV line is associated with the 44-sec Rh^{104} decay it will initially, after neutron irradiation, have a much greater (by a factor of approximately 70) relative intensity with respect to the Rh^{104m} transition than its equilibrium Rh^{104m}–Rh^{104} value. To determine whether this was the case, a further series of experiments was undertaken in which a 1-mg rhodium sample contained in a small gelatin capsule was irradiated for 3 sec and counted within 45 sec of the completion of the irradiation. An elapsed counting time of 1 min was used to accumulate four spectra in the time interval between 45 sec and 5.5 min after the source production. In another series using a similar rhodium source four spectra were accumulated in the time interval between 1 min and 7.5 min after the irradiation. In these two series, it was observed that the 96-keV line intensity remained constant with respect to the 52-keV Rh^{104m} line while the relative intensity of the 556-keV line produced in the β^- decay of the 44-sec Rh^{104} ground state was observed to decrease by a factor of approximately 11 during the first of these two series. From these experiments then the 96-keV line can definitely be assigned to the isomeric Rh^{104m} decay scheme.

B. Proportional Counter Spectra

In addition to obtaining gamma-ray spectra of Rh^{104m} with a NaI(Tl) scintillation detector as described in the previous section, it seemed worthwhile to obtain spectra with a proportional counter also, since a significantly better energy resolution is obtained with this latter instrument. A flow type proportional counter 5 in. in diameter by 12 in. long was available for these spectral measurements. The counter was equipped with 0.003-in.-thick Mylar entrance windows and had both guard and field electrodes to assure maximum energy resolution. In normal operation, a gas mixture of 90% argon and 10% methane was flowed through the counter at a pressure slightly above atmospheric pressure. With this arrangement, an energy resolution of 11% was obtained for the 14.4-keV line of Co^{57} while the iron K x ray had a half-width of 17%. In Fig. 3 a typical Rh^{104m} spectrum obtained with this proportional counter is shown. To obtain this spectrum, a source to window distance of 4 in. was used and a $\frac{1}{2}$-in.-thick Lucite beta absorber was located between the source and the counter. Additional spectra were obtained without the absorber, and also with a $\frac{1}{4}$-in. Lucite absorber. In Fig. 3 strong rhodium K_α and K_β x-ray peaks are observed while the 52-keV peak, although still clearly visible, has a much lower detection efficiency. The small peak at 8.0 keV can be attributed to copper and zinc K x rays produced in the brass components of the counter. The 77- and 96-keV lines are not observed in these proportional counter spectra because of the low detection efficiencies at these higher energies combined with their low intensities.

C. Coincidence Experiments

Coincidence studies of the Rh^{104m} gamma-ray spectrum were carried out using the thin window $1\frac{1}{2}$ in.$\times$1 in. NaI(Tl) detector in conjunction with a 3 in.$\times$3 in. NaI(Tl) crystal. The coincidence circuit used was of the fast-slow type and had a resolving time of 10^{-7} sec. In all of these coincidence experiments, the $1\frac{1}{2}$ in.$\times$1 in. NaI(Tl) crystal was used to feed the 512-channel pulse-height analyzer while the output of the 3 in.$\times$3 in. NaI(Tl) detector was analyzed by a single-channel pulse-height analyzer to select the energy region with which coincidences were to be studied. This coincidence arrangement was used with the Rh^{104m} sample located between the two crystals placed head-on to each other and with a separation of between $\frac{5}{8}$ in. and $\frac{7}{8}$ in. In addition, coincidence spectra were also taken for each "fixed" channel energy interval with the $\frac{1}{4}$-in. Lucite absorber between the sample and the 3 in.$\times$3 in. NaI(Tl) crystal, and also with a $\frac{1}{64}$-in. copper absorber between the source and either of the two crystals (which one depended upon the particular experiment). With this latter arangement, the probability of iodine K x rays escaping from one crystal and being detected in the

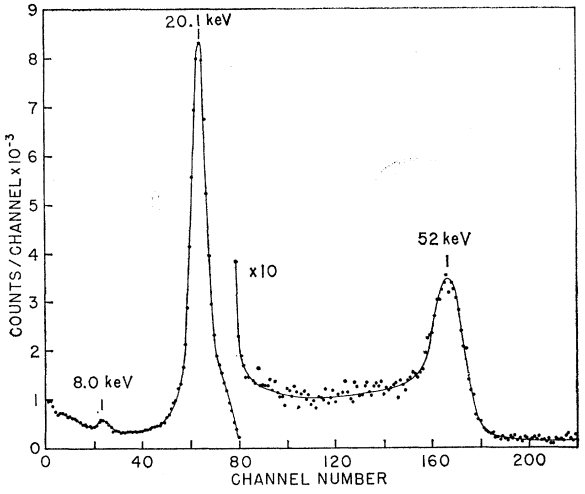

FIG. 3. Singles gamma-ray spectrum of Rh^{104m} obtained with a proportional counter.

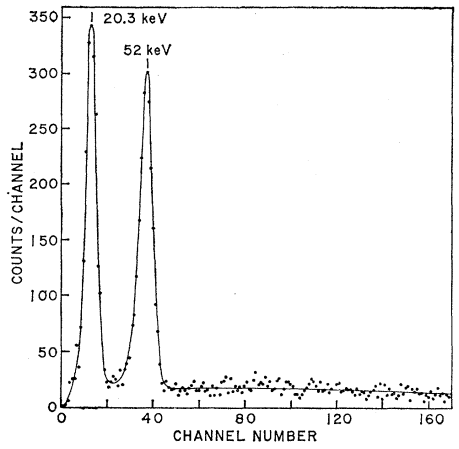

FIG. 4. The Rh^{104m} gamma-ray spectrum in coincidence with 77-keV gamma rays.

other was drastically reduced; thereby, simplifying the interpretation of these coincidence spectra.

The gamma-ray spectrum of Rh^{104m} in coincidence with the 77-keV line is shown in Fig. 4 for the case in which the $\frac{1}{64}$-in. copper absorber was located between the sample and the 3-in.×3-in. NaI(Tl) crystal. Spectra obtained without the copper absorber and with and without the $\frac{1}{4}$-in. Lucite absorber were similar to this spectrum. It will be noted that the rhodium K x-ray peak at 20.1 keV and the 52-keV peak from the Rh^{104m} spectrum sit on top of a continuum spectrum due to beta-gamma and gamma-gamma coincidences in the 44-sec Rh^{104} decay. That this was the case was determined from coincidence spectra obtained with the fixed channel level set above the Rh^{104m} part of the spectrum. In Fig. 4 there was no evidence of either the 77-keV line or the 96-keV line. The K internal conversion coefficient of the 52-keV transition could be determined from Fig. 4 after correcting the rhodium K x ray and 52-keV peak intensities for the iodine K x-ray escape peaks (including the 96-keV escape peak coincidence corrections), the fluorescence yield of rhodium K x rays, the self absorption in the rhodium, the attenuation through the intervening aluminum foil, etc. Corrections were also applied for the angular correlation between the coincident 77- and 52-keV gamma rays. From the known spins of the initial, intermediate, and final states in this cascade it was calculated with the aid of the tabulated values of $F_\nu(Lj_1j_2)$ given by Biedenharn and Rose[21] and from the tabulated Clebsch-Gordan and Racah coefficients[22] that the correlation function was $W(\theta)=1-0.188P_2(\cos\theta)$. Taking this function, coupled with the large acceptance angle of the NaI(Tl) detectors, a small correction could be assigned to the experimental K internal conversion coefficients of both the 52-keV transition and, later in this section, the 77-keV transition. With these corrections, the K internal coefficient of the 52-keV transition was measured as $0.89_{-0.09}{}^{+0.07}$. This value is to be compared with the theoretical K conversion coefficients of 0.79 for a 52-keV $E1$ transition and 1.95 for an $M1$ transition. Consequently this 52-keV transition can definitely be assigned as an $E1$ transition.

The gamma-ray spectrum of Rh^{104m} in coincidence with the 52-keV line is shown in Fig. 5 for the case in which a $\frac{1}{4}$-in. Lucite absorber is interposed between the source and the 3-in.×3-in. NaI(Tl) crystal. A very intense rhodium K x-ray line together with a weaker 77-keV line and a weak 50-keV line can be seen in Fig. 5. There is no evidence, however, of the 96-keV line in this spectrum. On calculating the escape peak corrections for this spectrum it becomes apparent that the 50-keV peak can be accounted for by two processes: (a) the escape peak of the 77-keV line and, (b) the 77-keV escape peak being detected in the 3-in.×3-in. NaI(Tl) crystal with either 52-keV gamma rays or rhodium K x rays being detected in the $1\frac{1}{2}$-in.×1-in. NaI(Tl) crystal. The K internal conversion coefficient of the 77-keV transition was determined from these coincidence spectra after correcting the gamma-ray intensities for the iodine K x-ray escape peak effects, the fluorescence yield of rhodium K x rays, rhodium self-absorp-

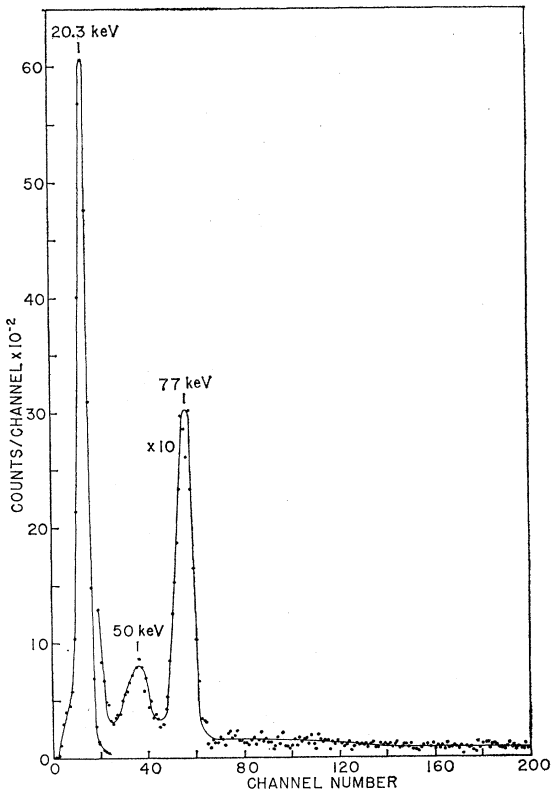

FIG. 5. The Rh^{104m} gamma-ray spectrum in coincidence with 52-keV gamma rays.

[21] L. C. Biedenharn and M. E. Rose, Revs. Mod. Phys. **25**, 729 (1953).

[22] M. Rotenberg, R. Bivens, N. Metropolis, and J. K. Wooten, Jr. *The 3-j and 6-j Symbols* (The Technology Press, Cambridge, Massachusetts, 1959).

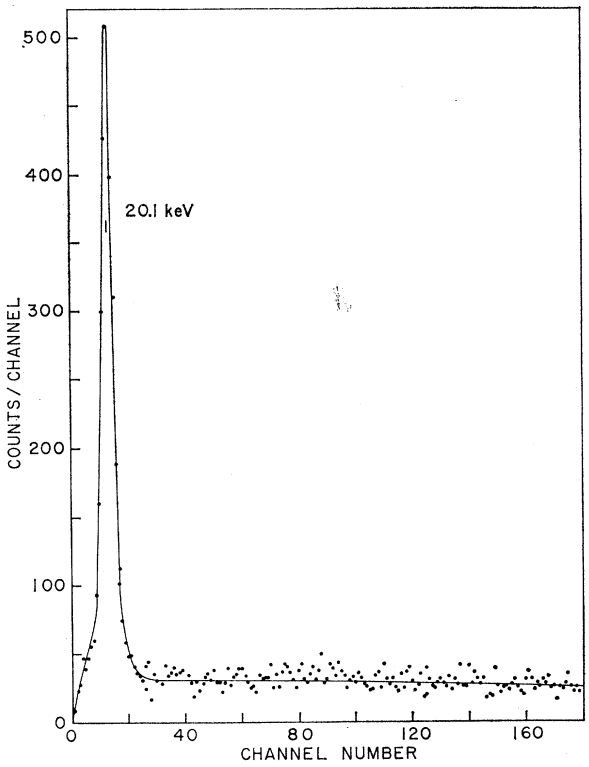

FIG. 6. The Rh^{104m} gamma-ray spectrum in coincidence with 96-keV gamma rays.

tion, attenuations, angular correlation corrections, etc. A value of 16.4 was calculated for the K internal conversion coefficient of the 77-keV transition. From the 4.4-min lifetime of the isomeric Rh^{104m} state, together with the experimental K/L internal conversion ratio, Jordan *et al.*[10] assigned the 77-keV transition as an $E3$ transition. This experimental K conversion coefficient agrees best with this assignment although it is smaller than the theoretical value[23,24] of 19.4.

In Fig. 6 the Rh^{104m} spectrum in coincidence with the 97-keV line is shown. This spectrum was obtained with the $\frac{1}{64}$-in. copper absorber located between the source and the 3-in.×3-in. NaI(Tl) crystal. The spectrum is seen to contain a rhodium K x-ray peak only, indicating that the 96-keV transition is in coincidence with a very highly converted transition, with an appreciable fraction of these transitions being K converted.

The gamma-ray spectrum of Rh^{104m} in coincidence with rhodium K x rays is shown in Fig. 7. With the exception that the rhodium K x-ray peak in the spectrum is severely attenuated, the coincidence spectrum with the $\frac{1}{64}$-in. copper absorber located between the source and the $1\frac{1}{2}$-in.×1-in. NaI(Tl) crystal is essentially similar to Fig. 7. It will be noted in Fig. 7 that the relative 96- to 77-keV peak intensity is approximately one-half that in the "single" spectrum shown in Fig. 2. Using this ratio, and taking into account the total internal conversion coefficient of the 52-keV transition, it can be calculated that the $(L+M+\cdots)/K$ internal conversion ratio for the highly converted transition in coincidence with the 96 keV is approximately 3.7.

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

[24] L. A. Sliv and I. M. Band, Leningrad Physico-Technical Institute Report, 1956 [translation: Report 57ICC $K1$, issued by the Physics Department, University of Illinois, Urbana, Illinois (unpublished)], Part 1.

INTERPRETATION

The 96-keV transition has been found to be in coincidence with a highly converted gamma transition only. Since such a cascade is not compatible with the known Pd^{104} level scheme,[15,16] and the transition intensity of the 96-keV gamma radiation is much greater than the 0.1% β^- transition of Rh^{104m} found by Bunker *et al.*,[14] this cascade must occur in the isomeric gamma decay of the Rh^{104m} level. A consistent isomeric gamma-decay scheme for Rh^{104m}, which incorporates this cascade, is shown in Fig. 8. An $E3$ or an $M3$ assignment to the 33-keV transition would be consistent with the observed transition intensity to the 96-keV level. In either case, the total internal conversion coefficient[23] of the 33-keV transition would be of the order of 7000. However, for such $E3$ and $M3$ transitions, the $(L+M+\cdots)/K$ conversion ratios would be approximately 84 and 2.8, respectively. By comparing these

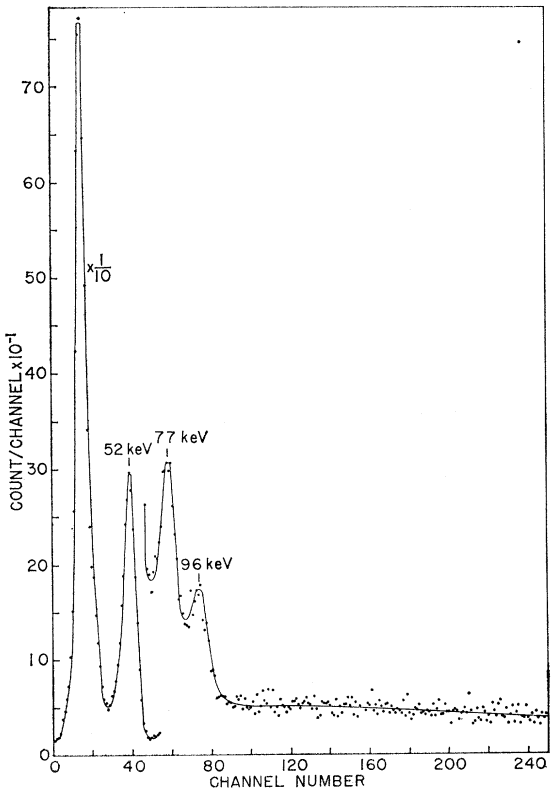

FIG. 7. The Rh^{104m} gamma-ray spectrum in coincidence with rhodium K x rays.

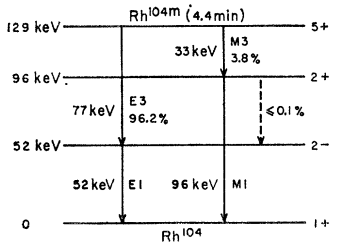

FIG. 8. The isomeric gamma-decay scheme of Rh^{104m}.

ratios to the experimental determination, from the coincidence studies, of the $(L+M+\cdots)/K$ conversion ratio as approximately 3.7, an $M3$ assignment can be made to the 33-keV transition. Since the 52- and 77-keV transitions have $E1$ and $E3$ multipolarity, respectively, a 2− spin and parity assignment can be made to the 52-keV level while the 129-keV level can be assigned as a 5+ state. Consequently, a spin and parity assignment of 2+ can be made for the 96-keV level.

Since the 77- to 52-keV gamma cascade is the primary cascade in the Rh^{104m} decay scheme, the corrected "singles" spectral intensities previously obtained, together with the K internal conversion coefficient of the 52-keV transition, can be used to obtain an independent determination of the K internal conversion coefficient of the 77-keV transition. It should be noted that, although the total and K internal conversion coefficients of the 77-keV transition were required to evaluate the rhodium K x ray plus 52-keV gamma ray real coincidence summing peak correction to the 77-keV peak, this correction was very small (of the order of 0.5 to 1.0% with a source to detector distance of 8 in.). Consequently, the previously determined experimental K conversion coefficient and the theoretical $(L+M+\cdots)$ conversion coefficient[23,25] of the 77-keV transition could be used for this small correction factor. From the "singles" spectral intensities then, the K internal conversion coefficient for the 77-keV transition was determined as 19.4 which is to be compared with the previously obtained coincidence result of 16.4. Combining these measurements, a resultant K internal conversion coefficient for the 77-keV transition of 17.9 ± 2.0 was obtained. This result is in excellent agreement with the theoretical value of 19.4 for an $E3$ transition.

The branching ratios shown in Fig. 8 were calculated using the "singles" spectral intensities, together with the experimentally determined K conversion coefficient of the 52-keV transition, the theoretical K conversion coefficient[23,24] of the 96-keV transition, and the theoretical $(L+M)$ conversion coefficients[23,25] of both these transitions. The upper limit of 0.1% on a possible 44-keV transition between the 96- and 52-keV levels was assigned from the probability that all of the 50-keV peak in Fig. 5 cannot be accounted for by escape peak processes.

It would be expected from the shell model that the ground-state configuration for the odd protons and neutrons would be $(g_{9/2})^5$ and $(g_{7/2})^3$, respectively, which since the ground-state spin and parity is 1+ would satisfy the modified Nordheim rules of Brennan and Bernstein.[26] However, from the adjacent odd-A nuclei with 59 neutrons, together with other odd-A, odd-N nuclei expected to have a $(g_{7/2})$ ground-state configuration, it can be concluded that the 59th neutron is actually in the $(d_{5/2})$ shell. This neutron configuration occurs because the $(g_{7/2})$ shell for neutrons tends to fill in pairs. But, a modified ground-state configuration of $(g_{9/2})^5(d_{5/2})^n$ could not account for the 1+ spin and parity of the ground state. From Rh^{103} and Rh^{105}, however, it is observed that the lowest $(g_{9/2})^5$ proton state has a seniority greater than one, with the total angular momentum coupling to 7/2. Therefore, the most probable assignment for the Rh^{104} ground state is $[(g_{9/2})^5]_{7/2}(d_{5/2})^n$. Because of the pairwise filling of the $(g_{7/2})$ neutron state, the neutron configuration in the ground state should more correctly be written as $(g_{7/2})^{9-n}(d_{5/2})^n$, where n is an odd integer with possible values of from one to five.

Both the 96- and 129-keV levels in Rh^{104} can also be assigned $[(g_{9/2})^5]_{7/2}(d_{5/2})^n$ configurations although, there is the possibility that one or both of these levels actually has a $(g_{9/2})^5(d_{5/2})^n$ configuration. A $(p_{1/2})(d_{5/2})^n$ configuration is the only acceptable assignment for the 52-keV level since all other possible negative-parity configurations require both the odd neutrons and odd protons to be in different configurations than in the 129-keV level and the ground state; in which case, the 77-keV transition would be expected to be greatly hindered, which is not the case. An additional confirmation of this assignment to the 52-keV state is that, of the possible negative-parity configurations, this is the only one which satisfies the modified Nordheim rules[26] by predicting a 2− state as the lowest energy level.

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