Decay Scheme of $_{45}Rh^{106}$*

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(Received August 14, 1947)

The decay scheme of $_{45}Rh^{106}$ (30*s*) is proposed as a complex beta-spectra with end points at 3.55 ± 0.10 and 2.30 ± 0.10 Mev. The latter is 18 ± 2 percent abundant and is followed by two gamma-rays 0.51 ± 0.02 and 0.73 ± 0.02 Mev in cascade, or a single 1.25 ± 0.05-Mev gamma. The 1.25-Mev gamma is present in 1–2 percent of the disintegrations. Evidence in support of the Gamow-Teller selection rules for beta-decay is given.

I. INTRODUCTION

IN 1942 B. L. Goldschmidt and I. Perlman[1] found two isotopes of Ru with half-lives of about 1 month and 3 months in U bombarded for 45 days with neutrons from 14-Mev deuterons on Be. The longer-lived one had associated with it a hard beta-ray which they reported as about 2.7 Mev from absorption measurements in aluminum.

L. E. Glendenin and E. P. Steinberg[2,3] made an investigation of the Ru from U bombarded at the Clinton Laboratories pile. They reported the longer-lived Ru as having a 330 d half-life and a 30 sec. daughter of Rh which gave beta-radiation with approximately 4-Mev maximum and gamma-radiation. Further work by Glendenin[1,4] characterized the radiation from the 30 sec. Rh as 20 percent of 2.8-Mev and 80 percent of 3.9-Mev betas as measured by absorption in aluminum and coincidence techniques, and also 0.3- and 0.8-Mev gamma-rays as measured by absorption in lead. According to Sleight *et al.*,[5] the radiations from the Ru have not yet been detected and hence are probably less than 5-kev maximum energy.

The mass assignment of 106 was made by Dempster[6] with a mass spectrometer.

Grummitt and Wilkinson[7] report a beta-ray maximum of 3.3 Mev and half-lives of 290 d and 30 sec. for Ru^{106} and Rh^{106}, respectively. The former differs from the current Project value of 1.0*y* as given in reference 3.

II. SOURCES AND APPARATUS

Rh^{106} in the sample used was in secular equilibrium with Ru^{106} and had been separated from other fission products in November 1945 by sulfide precipitation and two subsequent distillations. All observations here reported were made during May, 1947 so that all activities

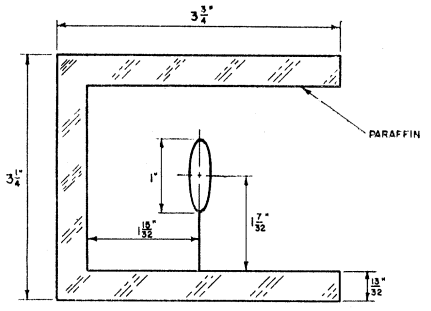

FIG. 1. Beta-ray source holder for spectrometer. (A beta-ray source is mounted on 50 g/cm² film and supported by the aluminum ring shown in the center of the figure.)

* This document is based on work performed under Contract No. W-35-058-eng-71 for the Atomic Energy Project at the Clinton Laboratories.

[1] From the Plutonium Project Report (PPR) Vol. 9B to be published shortly. This volume contains a complete report of Project information on the isotopes of Ru and Rh obtained in fission. B. L. Goldschmidt and I. Perlman, CC-295, Sept. 1942; PPR Vol. 9B, 7.18.1 (1946). A reference like the first refers to wartime reports of the Manhattan Project and one like the second reference is to papers prepared for the Plutonium Project Record (PPR), Vol. 9B, *Radiochemistry of the Fission Products*, in the process of being declassified and prepared for publication as part of the National Nuclear Energy Series, under the auspices of the United States Atomic Energy Commission.

[2] L. E. Glendenin and E. P. Steinberg, CC-579, p. 11, April 1943; CC-680, p. 9, May 1943; CC-920, p. 43, September 1943; Vol. 9B, 7.18.2 (1946).

[3] The numerical data bearing on decay characteristics, fission yields, and chain relationships of all known fission products are given by the Plutonium Project, Rev. Mod. Phys., **18**, 513–44 (1946) and also J.A.C.S., **68**, 2411–42 (1946).

[4] Plutonium Project Report, Rev. Mod. Phys. **18**, 526 (1946).

[5] N. R. Sleight, T. B. Novey, and L. E. Glendenin, PPR, Vol. 9B, 7.18.14 (1946).

[6] R. J. Hayden (working under the direction of A. J. Dempster), CP-3383, p. 4, December 1945.

[7] W. E. Grummitt and G. Wilkinson, Nature **158**, 163 (1946).

except Ru^{106} and Rh^{106} should have decayed to less than 1 percent of the total activity.

Approximately 50-μ curies of this activity were dried (at temperatures well below 150°C at which the Ru volatilizes) on to the center of a laminated film of polystyrene and Formvar one inch in diameter, and approximately 50-μ g/cm^2. The film was supported by a thin aluminum ring mounted as shown in Fig. 1. This served as a beta-source for a thin lens-type beta-ray spectrometer similar to that described by Deutsch *et al.*[8]

A spectrometer source was also prepared for the study of the gamma-rays by evaporating approximately 2 mc of the solution into a lead cup. This cup was thick enough to stop all the beta-rays at the source (1.8 g/cm^2). Electrons resulting from gamma-ray interactions in the lead were also analyzed in the spectrometer, and for a part of the time a thin uranium foil was put over the lead cup in order to increase the number of photo-electron interactions.

Annihilation radiation from the positrons of Cu^{64} (12.8 h) were used to calibrate the spectrometer. Thereafter, the beta-rays from P^{32} (14.3 d), mounted as in Fig. 1, were analyzed and found to form a straight line on a Kurie plot from their end point (1.72 Mev) to the point where the absorption caused by the counter window became appreciable (<150 kev).

Absolute gamma-counter efficiency as a function of gamma-ray energy was determined prior to the coincidence measurements using[9] Na^{24}, Co^{60}, I^{131}, and Au^{198}.

Beta-gamma, and gamma-gamma coincidence measurements were made using samples dried on 3 g/cm^2 polystyrene. The coincidence techniques used were similar to those used elsewhere.[9–11]

Coincidence and individual counting rates were recorded continuously on separate scaling circuits. The coincidence circuit had a resolving time of approximately one microsecond.

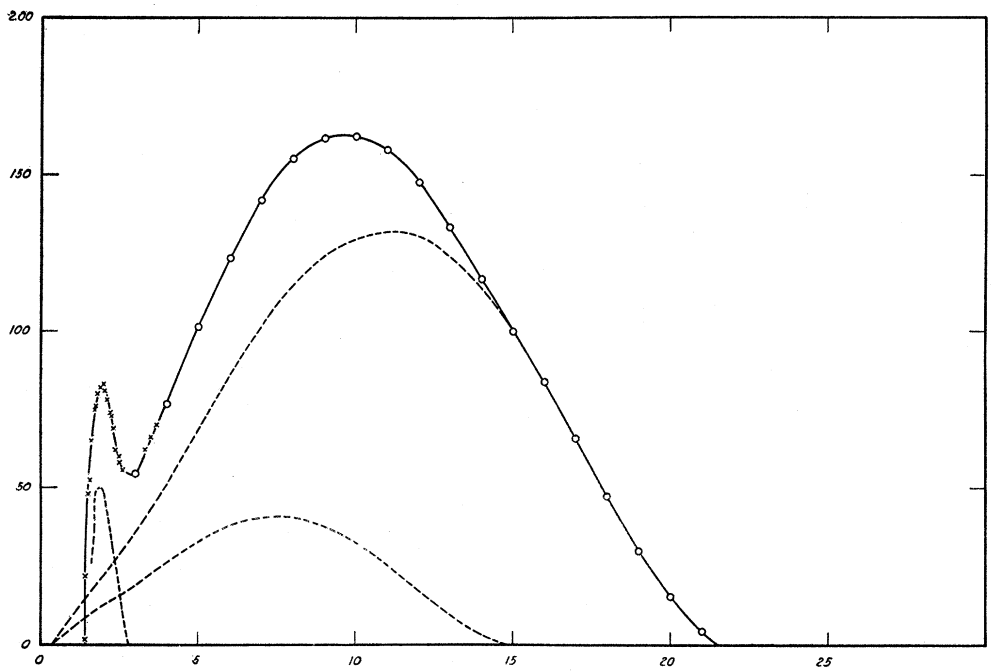

FIG. 2. Distribution of beta-rays from Rh^{106}. (The beta-spectra of Rh^{106} (30 sec.). Counting rate per unit momentum is plotted against coil current in amperes.)

[8] M. Deutsch, L. G. Elliott, and R. D. Evans, Rev. Sci. Inst. **15**, 178 (1944).
[9] A. Roberts, L. G. Elliott, J. R. Downing, W. C. Peacock, and M. Deutsch, Phys. Rev. **64**, 268 (1943).
[10] J. V. Dunworth, Rev. Sci. Inst. **11**, 167 (1940).
[11] A. Roberts, J. R. Downing, and M. Deutsch, Phys. Rev. **60**, 544 (1941).

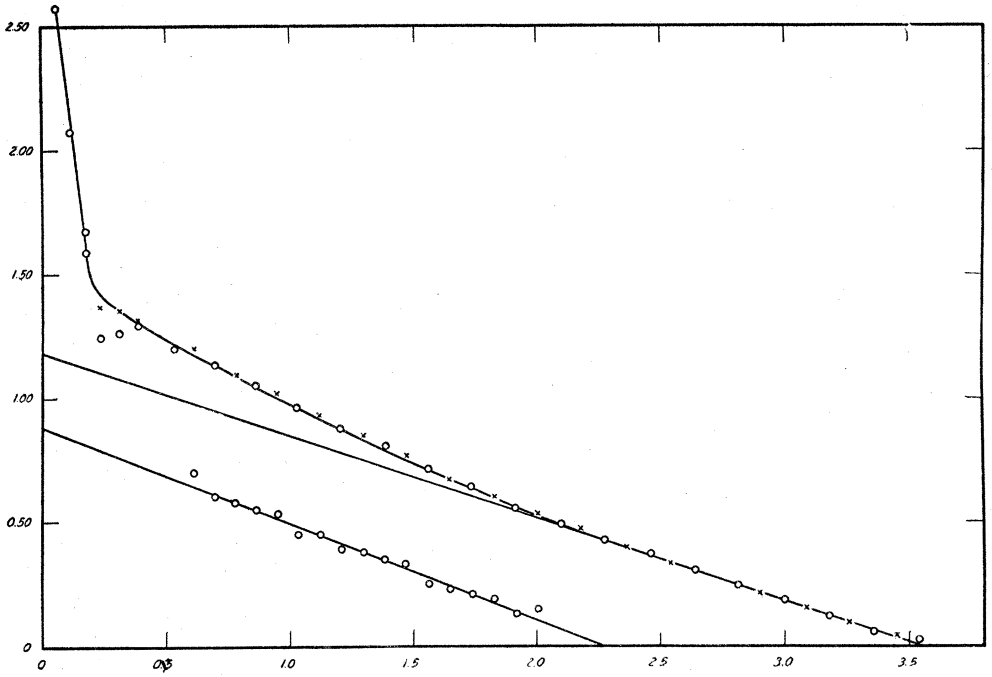

FIG. 3. Kurie plot of Rh^{106} beta-rays. (Kurie plot, $\sqrt{N/FI^3}$ *vs.* energy, E, where N is net counting rate, F is the Fermi function and I is coil current (α momentum of the electrons).)

III. RESULTS

The solid curve of Fig. 2 is a plot of the counts per minute per unit momentum interval, N/I *vs.* the current, I, in the spectrometer coil. (I is proportional to the momentum of the electrons.) The counter window for the run was 2.7 g/cm.[2] Figure 3 shows a Kurie plot taken from the same data. Above about 0.2 Mev this seems to be resolved into two beta-spectra with end points at 2.30 ± 0.10 Mev and 3.55 ± 0.10 Mev. The two spectra plotted as dotted lines in Fig. 2 are taken from points along the straight lines of Fig. 3. Relative areas under these two curves indicate 82 ± 2 percent of the beta-rays are related to the higher energy spectra and 18 ± 2 percent to the lower.[12]

Figure 4 shows the N/I *vs.* I curve for the electrons resulting from the interactions of the gamma-rays associated with Rh^{106} in lead. Points of particular interest are at A and B, where one sees K and L photo-electron peaks from a 0.51 ± 0.02-Mev gamma-ray, C, where one sees the K line from a 0.73 ± 0.02-Mev gamma-ray, and D, just beyond the Compton end point for a third gamma-ray, found to have an energy of 1.25 ± 0.05 Mev. The region between 4.5 and about 5.25 amperes includes Compton electrons from the 0.73-Mev gamma-ray as well as the peak from the photo-electron line of the 0.51-Mev gamma-ray. Uranium foil used as a radiator over the lead cup produced photo-electrons at C and D, making it possible to determine more accurately the energies of the 0.73- and 1.25-Mev gamma-rays. Relative intensities of the 0.51- and 0.73-Mev gammas are approximately the same, and that of the 1.25-Mev one is approximately 5–10 percent as abundant as either of them.

Coincidences between betas and gammas using 428 mg/cm² of Al before the beta-counter gave 0.19 ± 0.03 coincidence per 1000 betas, while using 6 mg/cm² of polystyrene and mica gave 0.44 ± 0.04 coincidences per 1000 betas.

These measurements indicate that as the ratio of lower to higher energy beta-rays entering to the beta-counter is increased (absorber decreased) the number of gamma-rays coinciding with the betas increases. This is confirmation that the beta-spectra is complex.

[12] The broad peak at 1 to 3 amperes seems to depend on source backing and is ascribed to back scattering.

From the known gamma-counter efficiency one would expect 0.71 ± 0.03 coincidence per 1000 betas coinciding with a 0.51-Mev gamma-ray, γ_1, 1.35 ± 0.06 coincidences per 1000 betas coinciding with 0.73-Mev gamma-ray, γ_2, and 3.37 ± 0.14 coincidences per 1000 betas coinciding with a 1.25-Mev gamma-ray, γ_3. If only 18 percent of the betas coincide with gamma-rays, of which about 10 percent are 1.25 Mev and the other 90 percent are 0.51 in cascade with 0.73 Mev, one would expect $(0.71+1.35)\times0.18\times0.90+3.37\times0.18\times0.10=0.40$ per 1000 betas. Gamma-counter efficiency under these conditions (with negligible absorber before the beta-counter) should be: $(0.71+1.35)\times10^{-3}\times0.90+3.37\times10^{-3}\times0.10=2.19\times10^{-3}$. Beta-counter efficiency is 0.166 ± 0.015. The net counting rate divided by efficiency, i.e., disintegration rate, would be

$$4405/0.166=26{,}500 \text{ by beta-emission,}$$
$$(10\pm1)/2.19\times10^{-3}=4560 \text{ by beta and gamma,}$$

or about 17 ± 2 percent of the disintegrations include gamma-rays.

Gamma-gamma coincidences per 1000 gammas with a cross-over gamma-ray should be given by

$$\frac{N_c}{N_\gamma/1000}=\frac{2KN_0\cdot e_1e_2\times1000}{N_0[K(e_1+e_2)+(1-K)e_3]}=0.80.$$

K is the fraction of gammas not in coincidence (taken as 10 percent) and the e's are the efficiencies of the counter for gammas of 0.51, 0.73, and 1.25 Mev, respectively. N_c and N_γ are the net coincidence and net gamma-counting rate, and N_0 is the disintegration rate by gamma-emission (lower beta-energy component of the disintegration). The value of $N_c/(N_\gamma/1000)$ found was 0.62 ± 0.05. This value is not in good agreement with the values to be expected, but may be accounted for by the bremstrahlung from the high energy, more abundant, beta-ray that was counted in the counters. (It would not be in coincidence with the gamma-rays and hence would decrease the coincidence rate per 1000 gammas.)

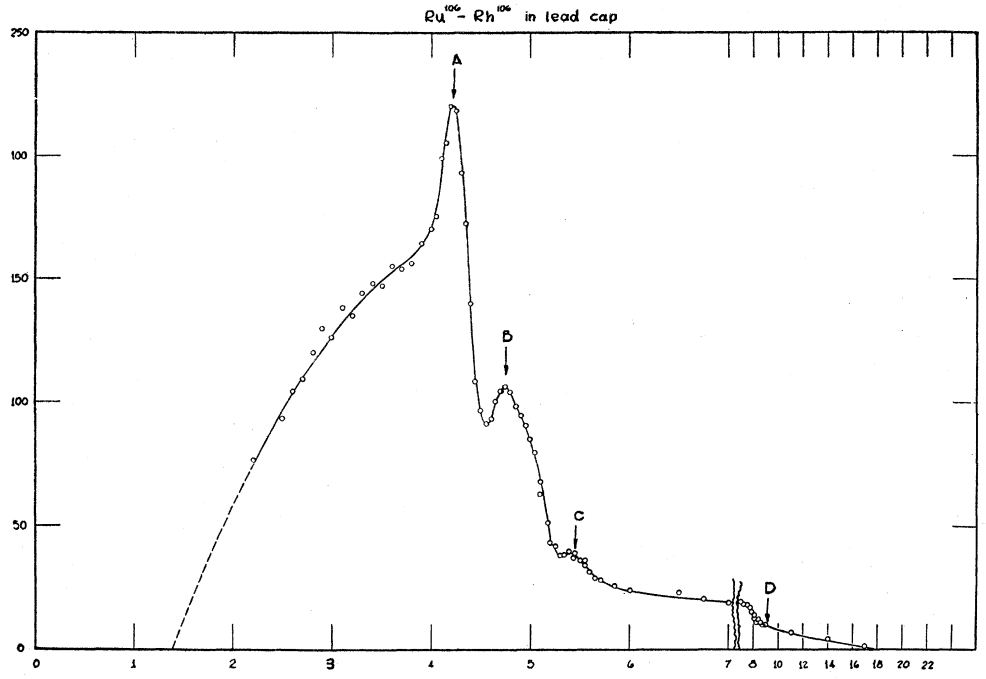

FIG. 4. Compton and photo-electrons from the Rh^{106} gamma-rays. (Electrons resulting from interactions of the Rh^{106} gamma-rays with lead. Counting rate per unit momentum is plotted against coil current in amperes. K photo-electrons are to be seen at A and C from 0.51- and 0.73-Mev gamma-rays. The end point for the Compton electrons from the latter gamma-ray and the L photo-electrons from the former are near B. D lies just beyond the Compton end-point for a 1.25-Mev gamma-ray.)

IV. DISCUSSION

It would seem that the decay scheme for Rh^{106} is probably as shown in Fig. 5.

If one computes the product *ft*, that is, Fermi function times the partial half-life, for the two beta-spectra, 3.55 Mev and 2.30 Mev,[13] one obtains 3310×36.6 sec. $=12.1\times10^4$ sec., and 533×167 sec. $=8.9\times10^4$ sec., respectively. Both of these values are in the range of values for allowed spectra (see reference 11, page 222).

One might further assume that the matrix elements for both processes were essentially the same, thus that both *ft* values would be approximately the same. Because of the errors in determining the beta-ray energies (ratio of relative abundances goes approximately as the fifth power of the energy ratio) and relative abundances, the *ft* values obtained cannot be considered significantly different.

Since the beta-spectra are allowed, they are accompanied by no nuclear-spin change if Fermi selection rules are obeyed. Now $_{46}Pd^{106}$ is an even-even nucleus, hence its ground state probably has zero total nuclear angular momentum ($J=0$). Fermi selection would seem, then, to require the 1.25-Mev gamma-ray to occur between two states with $J=0$. Such a $0\rightarrow0$ transition is completely forbidden for gamma-rays. According to the Gamow-Teller selection rules a spin change of 0, or 1 (no $0\rightarrow0$ change) can accompany either beta-decay. If one assumes, as before, that the ground state of the product nucleus has zero total nuclear angular momentum, then the state at 1.25 Mev above the ground level could have $J=1$ or 2. The value $J=0$ for the upper state is to be ruled out (gamma-transition $0\rightarrow0$ is completely forbidden as mentioned before). In either of the latter cases the 1.25-Mev gamma, γ_3, would be expected to be more abundant than the 0.51- and 0.73-Mev cascade, $\gamma_1+\gamma_2$, if both modes of decay involved the same spin and parity changes.

With either Fermi or Gamow-Teller selection rules an allowed beta-transition involves no parity change, so both the upper and lower states have the same parity. If $\Delta J=1$ between the upper and lower states, no parity change is forbidden for electric-dipole radiation and hence γ_3 must be magnetic-dipole radiation, if $\Delta J=2$ is electric-quadrupole radiation. Whether γ_3 is magnetic dipole or electric quadrupole, the only lower energy gamma-transition competing more favorably is electric dipole involving a parity change.[14] The transition $\gamma_1+\gamma_2$ (whichever is emitted first),[15] must then involve a spin change of $J=1$, and the intermediate excited state must have $J=1$, 2 or 3. (Here again the $J=0$ level would require the second gamma-ray to be a $0\rightarrow0$ transition.)

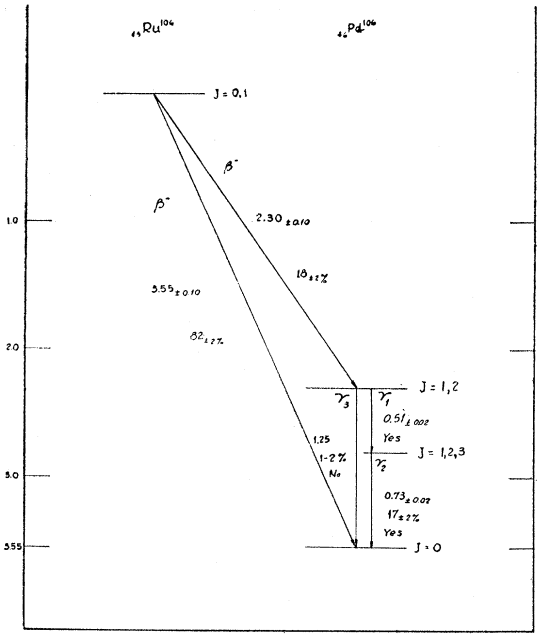

FIG. 5. Proposed decay scheme for Rh^{106}.

We wish to acknowledge the assistance of L. M. Gunning, J. W. Jones, and R. T. Overman.

[13] See for example, Eq. (24a) of E. J. Konopinski, Rev. Mod. Phys. **15**, 209 (1943).

[14] Magnetic 2^l-pole radiation is approximately as much less likely than electric 2^l-pole radiation as electric 2^{l+1}-pole radiation. Both such less-favored transitions should result in longer partial lifetimes with a ratio to the electric 2^l-pole radiation about the same.

[15] We have as yet no information about the order of emission of γ_1 and γ_2.