Title
SEARCH FOR A O+.2+, 4+ TRIPLET IN THE VICINITY OF 1.140 Mev IN Pd106.

Authors
Bosch, Horacio B.
Horen, Daniel J.

Publication Date
1960-09-01

UCRL 9385

UNIVERSITY OF CALIFORNIA

Ernest O. Lawrence

Radiation Laboratory

SEARCH FOR A 0^+, 2^+, 4^+ TRIPLET IN THE VICINITY OF 1.140 Mev IN Pd^{106}

DISCLAIMER

UCRL-9385
UC-4 Chemistry-General
TID-4500 (15th Ed.)

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

SEARCH FOR A 0^+, 2^+, 4^+ TRIPLET IN THE VICINITY OF 1.140 Mev IN Pd^{106}

Horacio E. Bosch and Daniel J. Horen

September 1960

SEARCH FOR A 0^+, 2^+, 4^+ TRIPLET IN THE VICINITY OF 1.140 Mev IN Pd^{106}

Horacio E. Bosch and Daniel J. Horen

Lawrence Radiation Laboratory
University of California
Berkeley, California

September 1960

ABSTRACT

The analysis of beta and gamma radiation coming from the disintegration of Rh^{106} has been studied by means of single and coincidence measurements with scintillation couters. A double level at an energy of 1.140 Mev in Pd^{106} was found. A disintegration scheme is proposed for the excited levels of Pd^{106} populated from Rh^{106}.

SEARCH FOR A 0^+, 2^+, 4^+ TRIPLET IN THE VICINITY OF 1.140 Mev in Pd^{106}*

Horacio E. Bosch† and Daniel E. Horen§

Lawrence Radiation Laboratory
University of California
Berkeley, California

September 1960

INTRODUCTION

This work is concerned with the search for a 0^+, 2^+, 4^+ triplet in the region of 1.130 Mev in Pd^{106}. Theoretically, such a triplet is expected on the basis of the work of Scharff-Goldhaber and Weneser,[1] Wilets and Jean,[2] Raz,[3] and Tamura and Komai.[4,5]

Experimentally, the levels of Pd^{106} can be reached by the decay of Rh^{106} (30 sec), Rh^{106m} (130 min), Ag^{106} (8.3 days), and Ag^{106m} (24 min). Only the decay of Rh^{106} (30 sec) is considered here.

Rhodium-106 (30 sec) is obtained from Ru^{106} (1 year), which decays to the former by a ground-state beta transition of 0.038 Mev. The beta spectrum of Rh^{106} was studied by Alburger[6] and Grigoriev et al.[7] Using photographic recording in a permanent-magnet spectrometer, Cork et al.[8] found two conversion lines of 0.510 and 0.621 Mev. The gamma spectrum has been studied by many authors, and a summary of their results is given in Table I.

Gamma-gamma angular correlation measurements have been performed with the cascading 0.510- and 0.621-Mev gamma rays arising from a level near 1.13 Mev,[9,10] and the experimental angular correlation fits the theoretical one, on the assumption of a $0 \longrightarrow 2 \longrightarrow 0$ cascade. Angular correlation with polarization was also performed with the same gamma rays,[11] leading to the conclusion that an excited state near 1.14 Mev of Pd^{106} is 0+, the first excited and ground states being 2^+ and 0^+, respectively.

---

*Work done under the auspices of the U. S. Atomic Energy Commission.

†On leave of absence from Departamento de Fisica, La Plata University, and fellow from Consejo Nacional de Investigaciones Cientificas y Technicas, Argentina.

§Sloan Foundation Postdoctoral Fellow for the year 1958-1959, Stanford University, Stanford, California. Now at the Lawrence Radiation Laboratory, University of of California, Berkeley, California.

TABLE I

Gamma rays from the disintegration of Rh^{106} according to different workers.

Alburger and Toppel (Ref.12)	Kahn and Lyon (Ref. 19)	Robinson, McGowan, and Smith (Ref. 15)	This work		Segaert et al. (Ref. 16)
			Relative intensities obtained by IBM code	Relative intensities obtained by hand subt.	
0.513 (100)	0.5200	0.513 (100)	0.514 (100)	0.514 (100)	0.513 (100)
0.624 (53)	0.620	0.624 (53±3)	0.626 (53±2)	0.626 (53±2)	0.624 (53±2)
0.870 (3)	0.880	0.876 (1.8±0.2)	0.870 (2.7±0.3)	0.870 (2.2±0.5)	0.865 (3.5±0.5)
1.045 (8)	1.040	1.053 (6.9±0.4)	1.050 (7.4±0.3)	1.050 (7.8±0.5)	1.045 (9±1)
1.131 (0.08)	1.140	1.130 (2.4±0.3)	1.140 (2.3±0.5)	1.140 (2.5±0.5)	1.14 (6.5±1.0)
				1.280 (0.4±0.2)	1.31 (0.8±0.3)
		1.49		1.490 (0.1±0.05)	
1.55 (2.5)	1.540	1.555 (0.65±0.05)	1.550 (1.2±0.2)	1.550 (0.9±0.21)	1.55 (1.5±0.3)
1.77 (1.0)	1.760	1.77 (0.19±0.03)	1.770 (0.35±0.05)	1.770 (0.26±0.04)	1.76 (0.2±0.07)
1.96 (0.6)		1.95 (0.10±0.02)	1.990 (0.20±0.05)	1.990 (0.10±0.05)	1.93 (0.18±0.06)
2.1 (0.5)		2.09 (0.13±0.02)	2.090 (0.20±0.05) 2.110 (0.20±0.05)	2.090 (0.10±0.05) 2.110 (0.17±0.05) 2.220 (0.06)	2.13 (0.3±0.1)
	2.28				
		2.36 (0.17±0.02)	2.360 (0.17±0.03)	2.360 (0.15±0.03)	2.3 2.37 } (0.6±0.1)
2.41 (1.0)	2.42		2.400 (0.3±0.05)	2.400 (0.25±0.05)	2.44 (0.03 ±0.01)
2.66 (0.2)		2.64 (0.03±0.01	2.660 (0.03±0.01)	2.660 (0.04±0.01)	2.63 (0.03±0.01
					2.88 (0.02±0.007)

The excited levels of Pd^{106} have also been studied by coulomb excitation. The first excited level at 0.513 ± 0.005 Mev was reached by bombarding palladium with 6-Mev alpha particles.[13] The second 2+ excited state at 1.128 ± 0.008 Mev was reached by Coulomb excitation of palladium with 8-Mev alpha particles.[14]

Recently, Robinson, McGowan, and Smith pointed out that the complex structure 0+,2+ at an energy of approximately 1.140 Mev in Pd^{106} can be detected simultaneously in the decay of Rh^{106} (30 sec).[15] Segaert, Demuynck, Hoogenboom, and Van den Bold studied the decay of Rh^{106} (30 sec).[16]

SINGLES MEASUREMENTS

A. Beta-Ray Spectrum

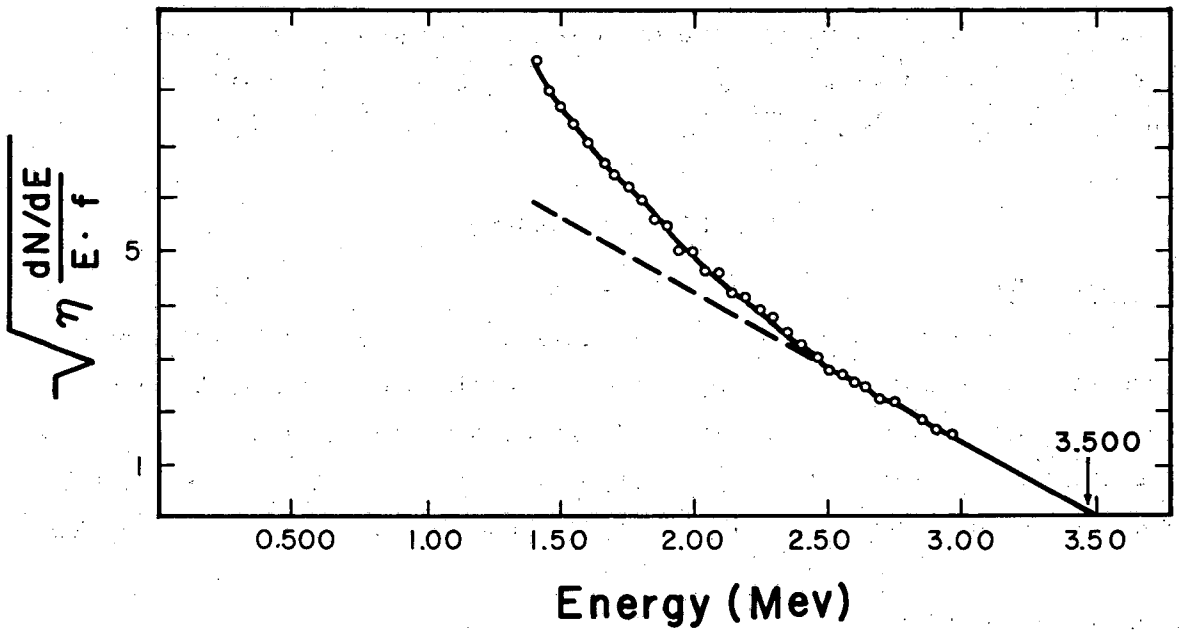
The end-point energy of the ground-state beta-ray transition was measured with a 2-inch diameter by 1-inch long plastic scintillator using collimated geometry. A typical Fermi-Kurie plot is shown in Fig. 1. The end-point energy was determined as 3.50±0.15 Mev. This value is in very good agreement with the results obtained with a magnetic spectrometer (3.53 Mev).[6,7]

B. Gamma-Ray Spectrum

Many single gamma-ray spectra were taken by utilizing different crystal sizes, geometries, and activities. The spectrum shown in Fig. 2 was taken with a 3-inch diameter by 3-inch long NaI(Tl) crystal, with a source-to-crystal distance of 60 cm. At this distance the solid-angle addition of the 0.510-0.625 Mev cascade was negligible.* Some of the singles spectra were analyzed both by hand and by IBM code.[17] The relative intensities of the gamma rays were obtained by use of the detection efficiencies given by Heath.[18] The results are given in Table I, where the agreement with the work of Robinson et al.[15] and Segaert et al.[16] is seen to be quite good. However, in this work the peak near 2.36 Mev appeared to be too broad for a single gamma ray, and analysis showed the presence of an additional gamma ray of 2.40 Mev. A peak at about

---

*In order to reduce the bremsstrahlung produced by the high-energy electrons, the source was sandwiched between two pieces of Be (2.340 g/cm^2).



MU-18950

Fig. 1. Fermi plot of the beta spectrum from Rh^{106} (30 sec) taken with a 2-inches diameter by 1-inch long plastic scintillator, using collimated geometry.

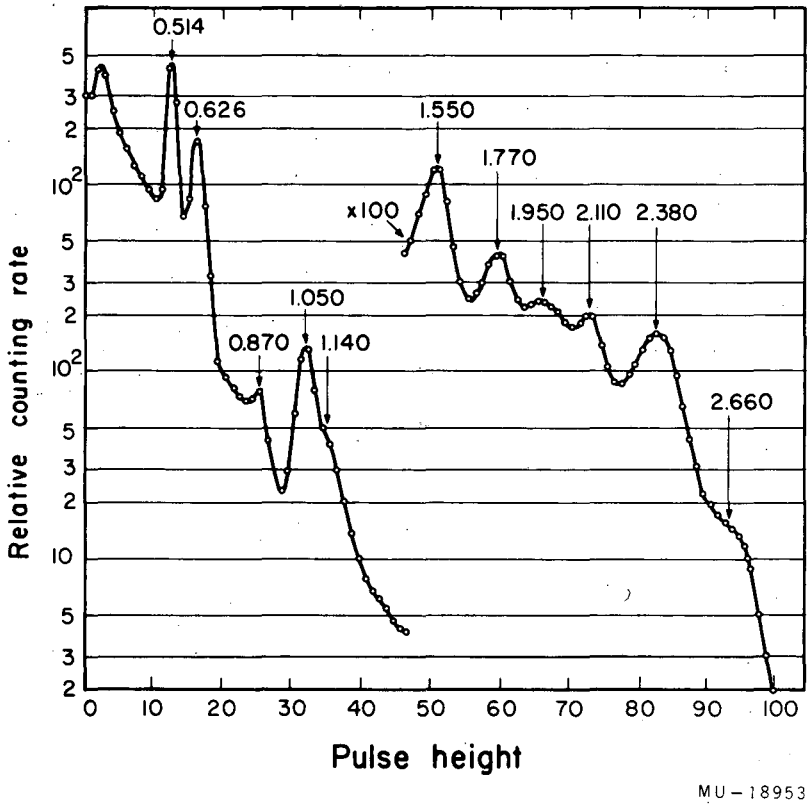


Fig. 2. Singles gamma-ray spectrum from Rh^{106} (30 sec) taken with a 3-inch diameter by 3-inches long NaI(Tl) and a multichannel pulse-height analyzer, at a source-to-crystal distance of 60 cm. The electrons have been absorbed with 2.350 g/cm^2 of Be.

1.28 Mev also appears in our data. Evidence of a gamma ray of this energy was also found in the gamma-gamma coincidence measurements. Further, there is an indication of gamma rays of 1.490, 2.110, and 2.220 Mev. However, their intensities are not sufficient to determine whether these peaks are real or due to poor analysis.

PERMANENT-MAGNET BETA-RAY SPECTROMETER MEASUREMENTS

An electroplated source of Rh^{106} was used to analyze the internal conversion lines in a permanent-magnet beta-ray spectrometer.

Different exposures were made and only two conversion lines were identified. The very intense continuum beta spectrum prevents observation of other weaker lines. The energies of the two lines observed were 0.514 Mev and 0.626 Mev, which correspond to transitions between the first excited level to ground level, and second excited level to the first, respectively.

COINCIDENCE MEASUREMENTS

A. Beta-Gamma Coincidences

Measurements were made of gamma rays in coincidence with beta rays of energies greater than about 1.84 Mev with different crystal sizes, geometries, and sources. A plastic scintillator 2 inches in diameter by 1 inch high coupled to a 6810-A photomultiplier was used to detect the beta rays; the gamma rays were detected in a 1-1/2-inch diameter by 1-1/2-inch long NaI(Tl) crystal coupled to a 6810-A photomultiplier. A slow-fast coincidence circuit ($2\tau \approx 50 m\mu s$) and a multichannel analyzer were used. Measurements were taken at 180-degree geometry, with collimator in the beta side and Be absorber in the gamma side. In one experiment, the geometry was such that the addition of the 0.626-0.514 cascade was appreciable, and data were taken with and without lead absorber in order to determine the intensity of the 0.626-Mev gamma ray relative to that of the 1.140-Mev gamma ray. The results obtained in this measurement were compared with those found in a better-geometry measurement in which the solid-angle addition was negligible. Figure 3 shows the gamma-ray spectrum in coincidence with beta rays of energy greater than 1.8 Mev, with good geometry. Analysis of all beta-gamma coincidence data yielded a value of 30±7 for the intensity of the 0.624-Mev gamma ray relative to that of the 1.13-Mev gamma ray, and about 8 for the intensity of the 1.045-Mev relative to the 1.55-Mev gamma ray.

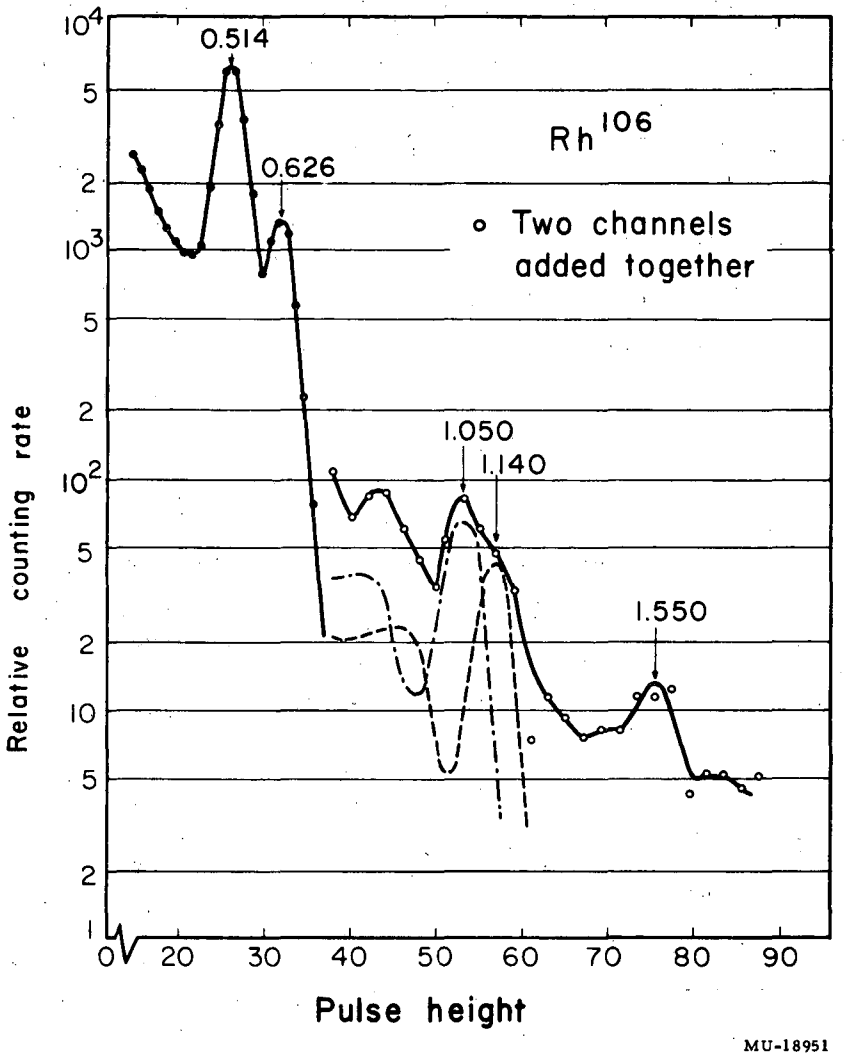


Fig. 3. Gamma-ray spectrum in coincidence with beta rays of energy greater than 1.8 Mev, in Rh^{106} (30 sec).

B. Gamma-Ray Coincidences

The gamma-gamma coincidence measurements were performed with a 3-inch diameter by 3-inches long NaI(Tl) crystal used as the discriminator, a 1-1/2 inch diameter by 1-1/2-inches long NaI(Tl) crystal used as the analyzer, a fast-slow coincidence circuit ($2\tau \sim 5 \times 10^{-8}$ sec), and a RCL 256-channel pulse-height analyzer. For most of the work, the crystals were placed at 90 degrees relative to each other with a 1/2-inch lead anti-scattering shield between them.

The discriminator was set at 0.51, 0.62, 0.87, 1.045, 1.14, and 1.55 Mev, with channel widths of about 40 to 60 kev. A summary of the gamma-gamma coincidence data is given in Table II. Some typical coincidence curves are shown in Figs. 4 and 5.

DISCUSSION

According to the analysis of the beta spectra from both Ru^{106} and Rh^{106}, the spin for Rh^{106} can be assigned as 1+. The ground state of Pd^{106} is assumed to be 0+, as in all even-even nuclei. The first excited state of Pd^{106} has an energy of 0.514 Mev, according to our determination of the conversion lines in the permanent-magnet beta-ray spectrometer. Moreover, the single gamma spectrum indicates that the 0.514-Mev ray is the most intense, and the gamma-gamma coincidences show that this transition corresponds to that between first excited and ground levels. Our studies of conversion lines in a permanent-magnet spectrometer indicate a transition of 0.626 Mev. Gamma-gamma coincidences show that this one sits above the 0.514 Mev level so a second excited level at an energy of 1.140 Mev is present.

Beta-gamma coincidence measurements indicate that beta rays of energy greater than 1.8 Mev are in coincidence with gamma rays of energies 0.514, 0.626, 1.05, 1.14 and 1.55 Mev. The gamma-gamma coincidence data, together with these results allows one to say that the 1.140-Mev gamma ray corresponds to a transition from the second excited state to the ground state. The singles spectrum shows a relative intensity $\gamma_{0.626} / \gamma_{1.140} = 22 \pm 2$. Beta-gamma coincidences show 30±7 for this ratio. Gamma-gamma coincidences gating at 0.870 Mev and 1.140 Mev indicate that the $\gamma_{0.626}/\gamma_{1.140}$ ratio is only about 2.2. This means that there are two 0.626-Mev gamma rays with relative intensities with respect to the 0.514-Mev gamma ray of 5.5% and 47.5%, respectively. This indicates that there are two levels near 1.140 Mev. One of them is supposed to be 2+ because there is a

TABLE II

Relative intensities of gamma rays in Rh^{106} decay

		Coincidences						
		Gamma rays (energy)						Beta spectrum
Energy	Singles	0.514	0.626	0.870	1.050	1.140 1.200	1.500 1.550	> 1.8 Mev
0.514	100		53		7.5	X	X	X
0.626	53±2	53		2.4		X	X	a
0.710			0.16					
0.870	2.4±0.5	2.4	2.4			1.1		
1.050	7.6±0.5	7.4						b
1.140	2.4±0.3		X	1.1		X	X	a
1.250	0.4±0.4	0.25						
1.500	0.1	0.2						
1.550	1.0±0.05							b
1.770	0.30±0.05	0.17						
1.990	0.15±0.05							
2.090	0.15±0.05							
2.110	0.18±0.05							
2.220	0.06							
2.360	0.16±0.05							
2.400	0.28±0.05							
2.660	0.03±0.01							

X: Coincidence observed.

a: Relative intensities of the two gamma rays marked thus are given in the text.

b: Relative intensities of the two gamma rays marked thus are given in the text.

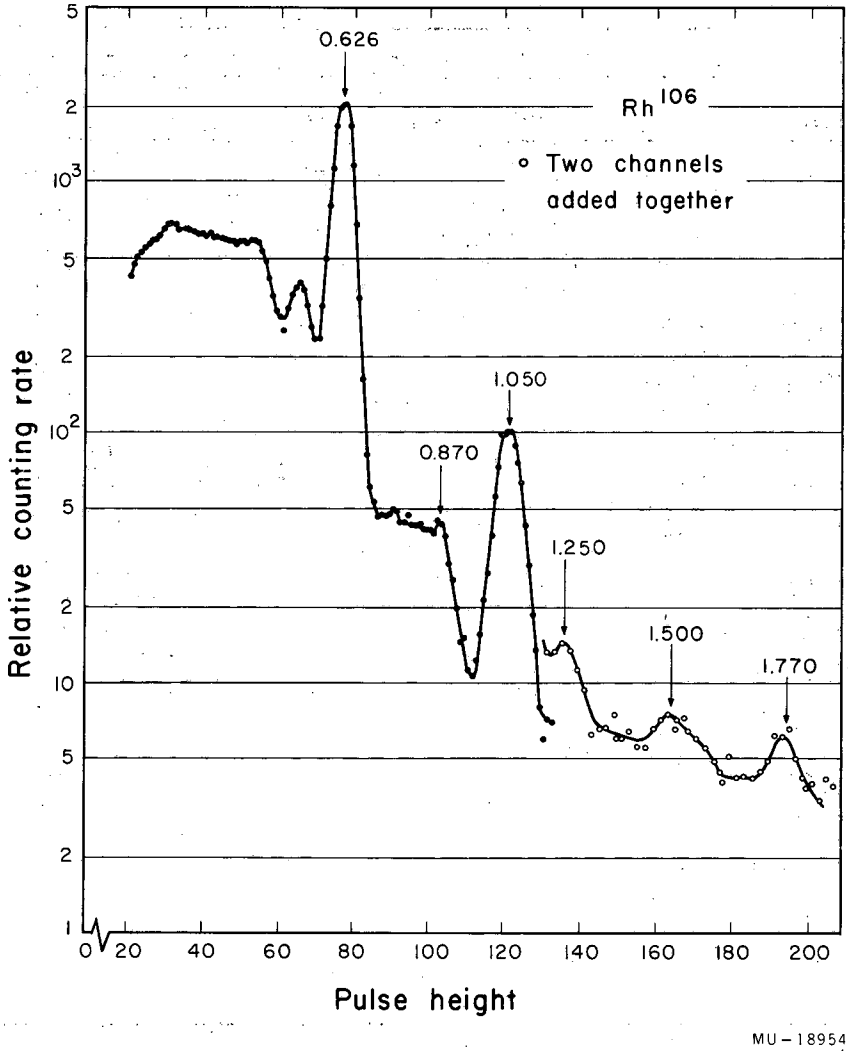


Fig. 4. Gamma-ray spectrum in coincidence with the 0.514-Mev gamma ray in Rh^{106} (30 sec).

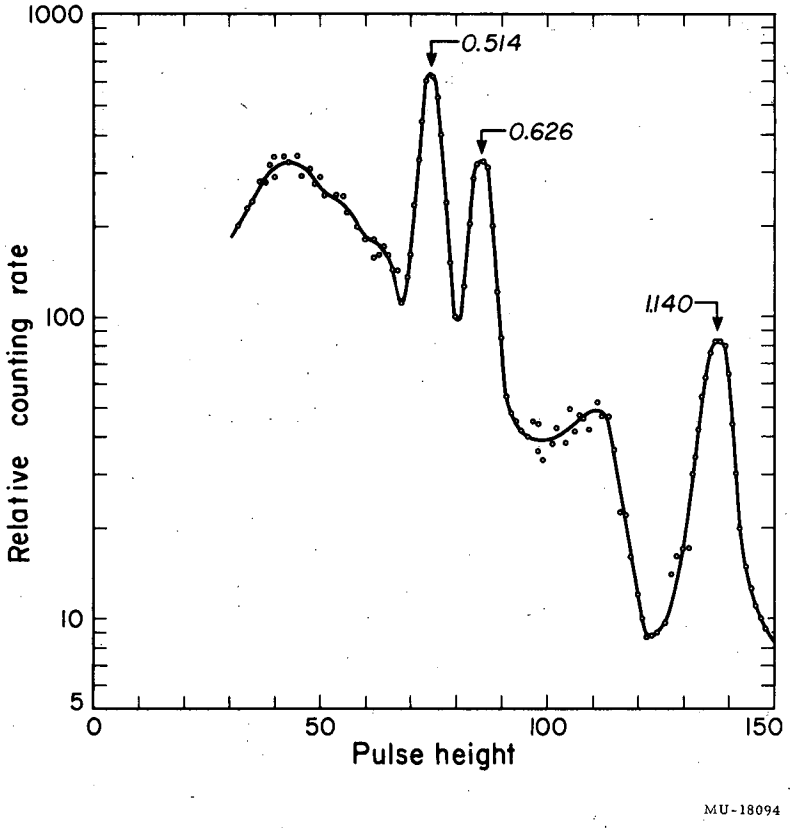


Fig. 5. Gamma-ray spectrum in coincidence with the gamma rays of 0.870 Mev, in Rh^{106} (30 sec).

cross-over transition to the ground level, and the other is supposed to be the 0+ level found in the angular-correlation experiments.[9,10] A third excited level at 1.550 Mev exists in Pd^{106}. According to our data, there is a cross over transition to the ground state. Gamma-gamma coincidences indicate the existence of higher levels in Pd^{106}. All these conclusions can be summarized in the proposed disintegration scheme for the low-lying levels in Pd^{106}, shown in Fig. 6.

ACKNOWLEDGMENTS

The authors wish to thank Dr. Carlos Mallmann for suggestions which led to the present work. They are also indebted to Dr. Richard Diamond and Dr. John Rasmussen for their interesting discussions during the course of the work. The cooperation of Dr. Jack Hollander in the analysis of the plates exposed in the permanent-magnet spectrometers is very much appreciated, as well as the preparation of the sources by Mab Tocher.

One of the authors (H.E.B.) wants to acknowledge the hospitality afforded to him by the Chemistry Department of the Lawrence Radiation Laboratory.

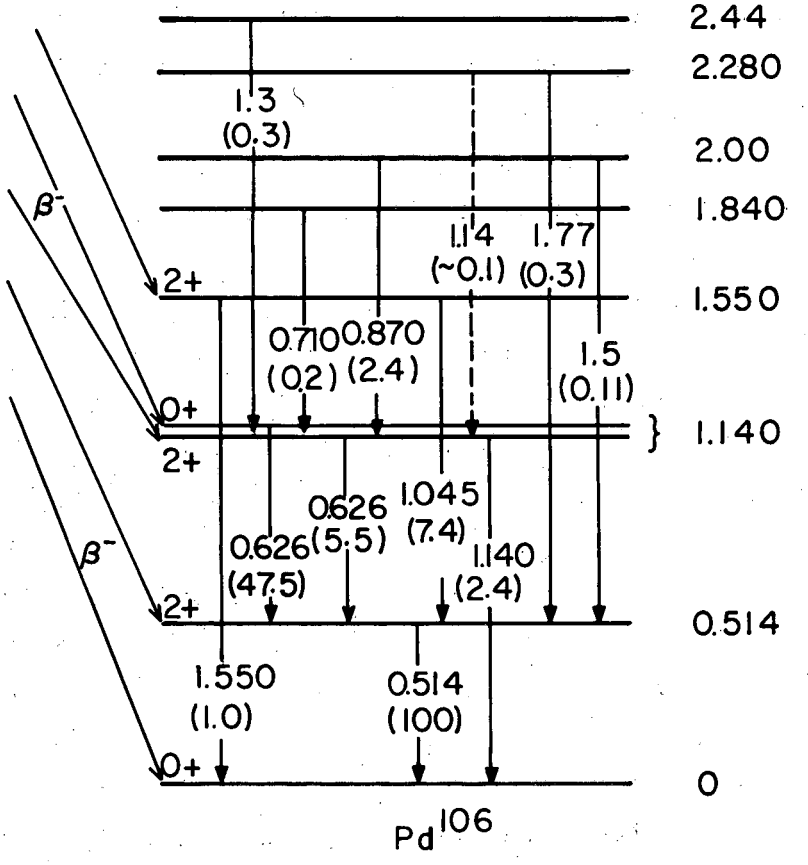


Fig. 6. Proposed disintegration scheme for the low-lying excited states of Pd^{106} populated from Rh^{106} (30 sec).

REFERENCES

1. G. Scharff-Goldhaber and J. Weneser, Phys. Rev. 98, 212 (1955).
2. L. Wilets and M. Jean, Phys. Rev. 102, 788 (1956).
3. B. J. Raz, Phys. Rev. 114, 1116 (1959).
4. T. Tamura and L. G. Komai, Phys. Rev. Letters 3, 344 (1959).
5. A summary is given by Horacio Bosch, Remarks on Excited States of Even-Even Nuclei and on the Existence of a Complex Vibrational Second Excited State, in UCRL-9074, Feb. 1960.
6. D. Alburger, Phys. Rev. 88, 339 (1952).
7. Grigoriev, Zolotavin, Kuzmin, and Pavlitskaia, J. Acad. Sci. (USSR), Physics Section 22, 194 (1958).
8. Cork, Le Blanc, Stumpf, and Nester, Phys. Rev. 86, 575 (1952).
9. J. J. Kraushaar and M. Goldhaber, Phys. Rev. 89, 1081 (1953).
10. E. D. Klema and F. K. McGowan, Phys. Rev. 92, 1469 (1953).
11. P. Stelson and F. K. McGowan, Bull. Am. Phys. Soc. 2, 267 (1957).
12. D. Alburger and P. R. Toppel, Phys. Rev. 100, 1357 (1955).
13. G. M. Temmer and N. P. Heydenburg, Phys. Rev. 104, 967 (1956).
14. P. H. Stelson and F. K. McGowan, Bull. Am. Phys. Soc. 2, 267 (1957).
15. R. L. Robinson, F. K. McGowan, and W. G. Smith, Bull. Am. Phys. Soc. Series II, 2, 279 (1959); Decays of Rh^{106} and Ag^{106} (to be published in Phys. Rev.). We would like to thank these authors for sending us a preprint of their paper prior to publication.
16. Segaert, Demuynck, Hoogenboom, and Van den Bold, Nuclear Phys. 16, 138 (1960).
17. Harry West (Lawrence Radiation Laboratory, Livermore), private communication.
18. R. L. Heath, "Scintillation Spectrometry Gamma-Ray Spectrum Catalogue" IDO-16408, July 1, 1957.
19. B. Kahn and W. S. Lyon, Phys. Rev. 92, 902 (1953).