

Decay of Ir¹⁹⁶†

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(Received 18 December 1964)

Iridium-196 (120 min) has been produced by the (d,α) reaction on Pt¹⁹⁸. The iridium was chemically separated from the target material. Gamma-ray, beta-ray, gamma-gamma, beta-gamma, and gamma-ray sum coincidence spectra were measured. Ir¹⁹⁶ decays by a single beta group with an end-point energy of 0.95 MeV. The beta decay is followed by a cascade of six gamma rays of 100, 355, 389, 442, 518, and 646 keV. This decay is compatible with the known level scheme of Pt¹⁹⁶.

I. INTRODUCTION

THE only iridium nuclide which would be expected to have a half-life greater than a few minutes and which has not been characterized is Ir¹⁹⁶. Butement and Poe¹ assigned to Ir¹⁹⁶ a 9.7-day activity which they produced by irradiating platinum with high-energy neutrons and with gamma rays. Gardner's² attempts to find Ir¹⁹⁶ in platinum foils which had been bombarded with deuterons were unsuccessful; however, he was able to set an upper limit of 5 h for the half-life. Gardner also attributed the 9.7-day activity to Ir¹⁸⁹. The decay of Ir¹⁹⁶ populates levels in Pt¹⁹⁶. These levels have been studied by (d,p) reactions³ on Pt¹⁹⁵ and through the decay^{4,5} of Au¹⁹⁶.

In the present work Ir¹⁹⁶ was produced through the reaction Pt¹⁹⁸(d,α)Ir¹⁹⁶. This nuclide was shown to decay with a half-life of 2 h by a single beta group followed by a cascade of six gamma rays.

II. SOURCE PREPARATION

The Ir¹⁹⁶ was produced by irradiation of platinum metal with 20-MeV deuterons from the Brookhaven 60-in. cyclotron. The targets for most of the bombardments were cut from commercial platinum foil of natural isotopic composition. Other targets were prepared by electrodeposition⁶ of platinum enriched⁷ in Pt¹⁹⁸ onto copper foils. Spectrographic analysis of both natural and enriched platinum showed that both osmium and iridium were below the limits of detection, 0.01%.

It was necessary to separate the iridium from the large amounts of gold and platinum activities produced from the (d,xn) and (d,p) reactions, respectively. Some

Na²⁴ and Mg²⁷, which recoiled from the aluminum face plate of the cyclotron, were also found. The copper backing of the enriched platinum targets was a source of various zinc and copper activities. The separation procedure given below is a combination of the methods of Gardner² and of Busch, Prospero and Naumann.⁸

The platinum was dissolved in boiling aqua regia and carriers of iridium, gold, sodium, magnesium, zinc, and nickel were added. The solution was evaporated to dryness, taken up in 12*N* HCl, evaporated to dryness, and taken up in 3*N* HCl. Gold was removed by four ethyl-acetate extractions. Stannous chloride was added and platinum was extracted into ethyl acetate six times. The resulting aqueous solution was placed on an ion-exchange column of 1.5 cm² cross-sectional area filled to 12 cm with Dowex 1×8, 50–100 mesh topped with 12 cm of Dowex 50W×8, 50–100 mesh. Iridium was eluted with 9*N* HCl. Sufficient base was added to lower the acid concentration to about 1.5*N*, and the iridium was reduced to the elemental state with magnesium. The precipitate was collected on a glass fiber filter and thoroughly washed with water, 7*N* nitric acid, water, and acetone. This gave a disc-shaped counting sample, 2 cm in diameter. Samples prepared in this manner were very pure radiochemically, containing only Ir¹⁹², Ir¹⁹⁴, and Ir¹⁹⁶.

III. GAMMA RAY SPECTROMETRY

The gamma-ray spectra were recorded on a 400-channel pulse-height analyzer using 7.6-cm×7.6-cm cylindrical NaI crystals. Aluminum absorbers were used to shield the gamma detectors from the high-energy beta rays of Ir¹⁹⁴. The source was centered on the detector axis at a distance of 9.0 cm.

Figure 1 shows the spectrum of the iridium fraction from a natural target. Curve A was recorded 80 min. after the end of bombardment and contains both Ir¹⁹⁴ and Ir¹⁹⁶. Curve B was taken 24 h after end of bombardment and is due almost entirely to Ir¹⁹⁴. Ir¹⁹² is present in about 5% of the Ir¹⁹⁴. Curve C was obtained by subtracting spectrum B, corrected for the decay of Ir¹⁹⁴, from spectrum A and is the spectrum of Ir¹⁹⁶. Figure 2 shows the spectrum of the iridium fraction

† This work was performed under the auspices of the U. S. Atomic Energy Commission.

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¹ F. D. S. Butement and A. J. Poe, *Phil. Mag.* **45**, 31 (1954).

² D. G. Gardner and W. W. Meinke, *Phys. Rev.* **114**, 822 (1959).

³ B. L. Cohen and R. E. Price, *Phys. Rev.* **118**, 1582 (1960).

⁴ H. Ikegami, K. Sugiyama, T. Yamazaki, and M. Sakai, *Nucl. Phys.* **41**, 130 (1963).

⁵ A. H. Wapstra, J. F. W. Jansen, P. F. A. Goudsmit, and J. Oberski, *Nucl. Phys.* **31**, 575 (1962).

⁶ A. G. Gray, *Modern Electroplating* (John Wiley & Sons, Inc., New York, New York, 1953), p. 358.

⁷ This material, consisting of 56.8% Pt¹⁹⁸, 26.7% Pt¹⁹⁶, 11.6% Pt¹⁹⁵, and 4.9% Pt¹⁹⁴ was supplied by the Isotopes Division, Oak Ridge National Laboratory, Oak Ridge, Tenn.

⁸ D. D. Busch, J. M. Prospero, and R. A. Naumann, *Anal. Chem.* **31**, 884 (1959).

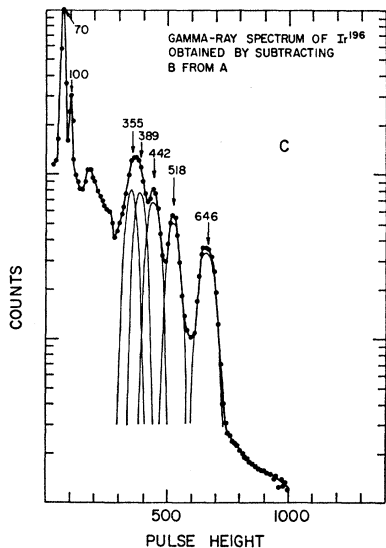
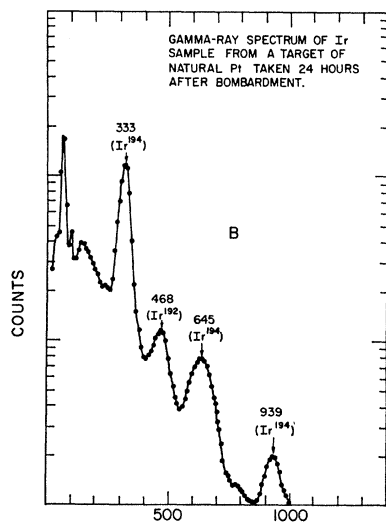
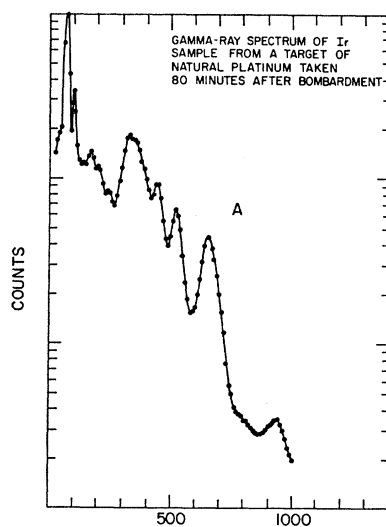


FIG. 1. Gamma-ray spectrum of Ir sample from a target of natural Pt. Curve A was taken 80 min after bombardment, curve B was taken 24 h after bombardment, and curve C was obtained by subtracting B, corrected for the decay of Ir¹⁹⁴, from A.

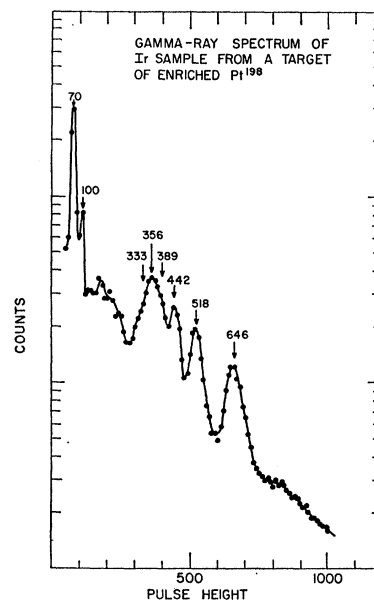


FIG. 2. Gamma-ray spectrum of Ir sample from a target of enriched Pt¹⁹⁸.

from an enriched platinum target. This curve was recorded 100 min after the end of bombardment and other than a 10% contribution due to Ir¹⁹⁴ is identical to curve C of Fig. 1.

Spectral analysis was done by using Gaussian shapes for the full-energy peaks and by matching the Compton distributions with those of standards run under the same experimental conditions. The energies and intensities of the prominent gamma-ray peaks are listed in Table I. In the region of 300–700 keV the distribution is well accounted for. At lower energies the multiple subtractions produce errors of such magnitude that weak transitions could not be distinguished. After subtraction of the background and summing effects no gamma rays above 700 keV were found. Upper limits of 10% and 5% of the 646-keV transition were set for gamma rays between 100 and 300 keV and greater than 700 keV, respectively.

Five of the gamma rays are listed as being approximately equal in abundance. Comparison of gamma- and beta-ray intensities indicates that the absolute intensity of these gamma rays is approximately 100%. The low

TABLE I. Summary of Ir¹⁹⁶ gamma-ray data.

Gamma-ray energy (keV)	Single-crystal intensity ^b	Coincidence quotient ^a with gamma rays of energy (keV)				
		370 ^c	385	442	518	646
70	160 ± 10	0.6	0.6	0.5	0.4	0.6
100	33 ± 5	0.3	0.3	0.3	0.3	0.4
355	102 ± 3	0.9	1.0	1.9	2.0	2.0
389	95 ± 3					
442	95 ± 3	0.9	1.0	...	1.0	1.0
518	98 ± 3	0.9	1.1	1.1	...	0.9
646	100	1.0	0.9	1.0	1.1	...

^a The error index for the coincidence quotients is ±0.2.

^b Relative to the 646-keV gamma ray as 100 units.

^c See text for the explanation of window energy.

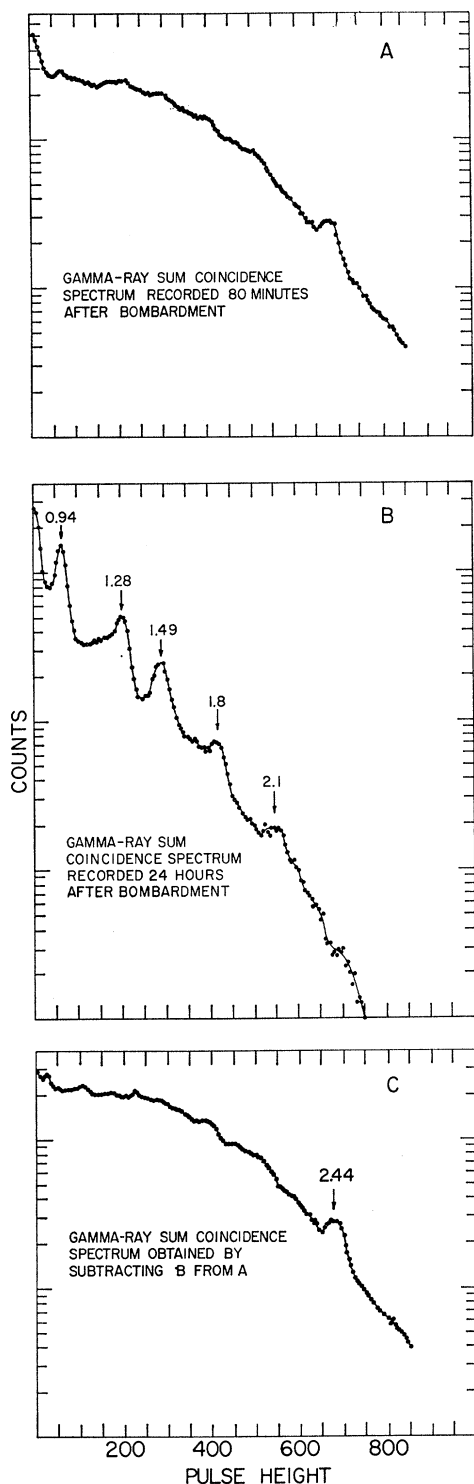


FIG. 4. Gamma-ray sum coincidence spectrum. Curve A was recorded 80 min after bombardment, curve B was recorded 24 h after bombardment, and C was obtained by subtracting B, corrected for the decay of Ir¹⁹⁴, from A.

The backscatter effect was considered sufficiently small to be ignored. The peak efficiencies were determined from the total gamma efficiencies and peak-to-total

ratios given by Heath.⁹ These values, corrected for attenuation in the copper absorbers, and the photopeak areas from the single-crystal spectrum were used to determine the disintegration rate. The measured sum-peak intensity is 422 counts/min compared with the calculated value of 394 counts/min. The 100-keV photons are shown to be of low relative abundance and this is attributed to partial internal conversion of this transition. This does not appreciably affect the sum peak calculation as the x ray¹⁰ accompanying internal conversion would give a sum peak with essentially the same energy as would the 100-keV gamma ray.

IV. BETA-RAY SPECTROMETRY

The beta spectra were recorded using either a Pilot B scintillator or an anthracene crystal. The electronic system was the same as that used for gamma-ray spectrometry.

The beta spectrum of the iridium fraction from a natural platinum target is shown in Fig. 5, where curve A was recorded 90 min after end of bombardment and curve B was recorded 24 h after end of bombardment. The determination of the end point of the Ir¹⁹⁶ beta rays is complicated by the large amount of Ir¹⁹⁴ present. To circumvent this problem the spectrum of curve B was corrected for the decay of Ir¹⁹⁴ and subtracted from that of curve A. The Fermi plot of the resulting Ir¹⁹⁶ spectrum is shown as curve C of Fig. 5. The Fermi plot of

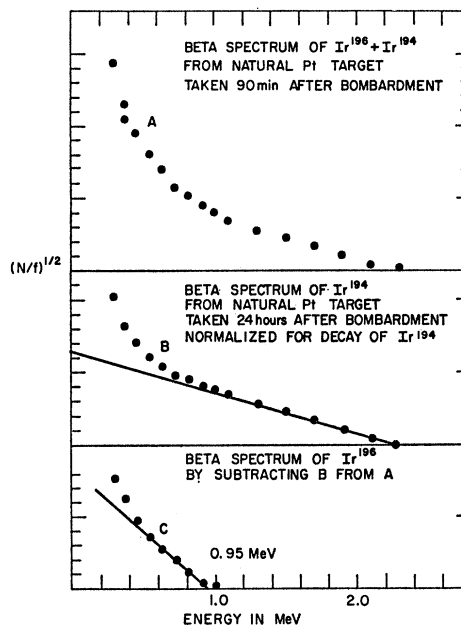


FIG. 5. Beta spectrum of Ir¹⁹⁶ and Ir¹⁹⁴ from a natural platinum target. Curve A was recorded 90 min after bombardment. Curve B was recorded 24 h after bombardment and has been corrected for the decay of Ir¹⁹⁴. Curve C was obtained by subtracting B from A.

⁹ R. L. Heath, *Scintillation Spectrometry Gamma Ray Spectrum Catalogue* (Office of Technical Services, U. S. Department of Commerce, Washington, D. C.), IDO-16880-1.

¹⁰ The fluorescence yield for K x rays in Pt is 0.94. C. D. Broyles, D. A. Thomas, S. K. Haynes, *Phys. Rev.* **89**, 715 (1953).

the various nuclear models so that the low-lying states are well fitted, it is possible to calculate the energies of some of the higher levels. The 355-, 689-, 874-, and 1002-keV levels were used to determine the parameters for each model. The asymmetric rotor model of Davydov and Filippov¹³ does not give a consistent set of parameters; however, when a first-order rotational-vibrational interaction¹⁴ is included, an adequate fit for the four levels is obtained. The general asymmetric rotor model of Mallmann¹⁵ and the nonadiabatic rotor model of Davydov and Chaban¹⁶ are similar and give similar results. The calculated energies are given in Table II.

The calculations give weight to assigning the 646-keV gamma ray to the transition between the 1520- and 874-keV levels. In order to use calculated energies to place the remaining gamma rays in a level scheme, the calculations must be accurate to a few percent. This is the magnitude of the errors for the known levels and thus the calculated energies for higher states are not expected to have the necessary accuracy. The conversion coefficient of approximately 2 for the 100-keV transition is consistent with an *E2* assignment.

A level can be placed at 2.45 MeV which probably has a spin of 9 to 12. This is the level of Pt¹⁹⁶ which is populated in the beta decay of Ir¹⁹⁶. The *logft* value of 6.0 indicates that the beta decay must be either allowed or first forbidden, and that the level of Ir¹⁹⁶ which is depopulated must also be a high-spin state.

The ground-state character of odd-odd nuclei frequently can be predicted by applying the coupling rules proposed by Gallagher and Moszkowski¹⁷ to the Nilsson orbitals¹⁸ assigned to the odd proton and neutron. The odd mass Ir nuclei are $\frac{3}{2} + [402\downarrow]$ in character and based on the ground state spins of the isotones of Ir¹⁹⁶, the odd neutron would be either $\frac{3}{2} - [512\downarrow]$, $\frac{5}{2} - [503\downarrow]$, or $\frac{1}{2} - [510\uparrow]$, which would give a ground state spin of 3-, 4-, or 1-.

Although Scharff-Goldhaber, Takahashi, and McKeown¹⁹ have shown that the ground state spins of the other odd-odd Ir nuclei, with the exception of Ir¹⁹⁴, cannot be explained in this manner, it is still questionable to assign a spin of 9 to 12 to the ground state of

TABLE II. Comparison of calculated and experimental values for some energy levels of Pt¹⁹⁶. The energies are in keV. Square brackets indicate the percentage differences from the experimental values. The values of the parameters for each model are given.

<i>I</i> <i>k</i>	Experimental energy ^a	Perturbed Davydov-Filippov ^b	Davydov-Chaban ^c	Mallmann ^d
20	356	358[0.6]	355[0.3]	355[0.3]
22	689	689[0.0]	689[0.0]	688[0.1]
32	1002	991[1.1]	1023[2.1]	991[1.1]
40	878	884[0.7]	874[0.5]	879[0.1]
60	...	1514	1535	1495
		$\gamma = 30^\circ$ $b = 1.0 \times 10^{-4}$	$\gamma = 30^\circ$ $\mu = 0.28^\circ$	$A/C = 4.2$ $k = 0.9$ $hc = 30.1$ $b = 9.8 \times 10^{-4}$

^a The experimental energy values are those of Ikegami *et al.* (Reference 4).

^b Reference 14.

^c Reference 16.

^d Reference 15.

Ir¹⁹⁶ as no other Ir nuclide has such a high ground-state spin, and only Ir¹⁸⁶ has a ground-state spin greater than 4.

Relatively low-lying levels of high spins are not uncommon in Ir nuclei, cf. Ir¹⁹² and Ir¹⁹⁰. A decay scheme which would fit the data for Ir¹⁹⁶ might be very similar to that of Ir^{190m} (3 h)²⁰; although the isomeric level of Ir¹⁹⁶ could be much lower in energy and still populate high-spin states in Pt¹⁹⁶.

It is interesting to note that several workers^{1,21} have found a 2.3 h iridium activity which was assigned to Ir¹⁹⁵. The beta-ray energy as well as some of the gamma rays reported by these authors agree with this work, and it is felt that their activity, which was assigned to Ir¹⁹⁵, was in fact Ir¹⁹⁶. Claffin, White, and Pool²² have characterized Ir¹⁹⁵ and have shown it to have none of the properties of the 2.3 h activity.

ACKNOWLEDGMENTS

The author would like to express his thanks to Dr. C. P. Baker and the staff of the Brookhaven cyclotron for technical advice and many bombardments, J. R. Holder for assistance with data processing, Dr. G. T. Emery, Dr. M. Hillman, Dr. B. M. Gordon, and Dr. R. L. Kiefer for helpful criticism of the manuscript, and Dr. P. Mukharjee for furnishing his results before publication.

²⁰ *Nuclear Data Sheets*, compiled by K. Way *et al.* (Printing and Publishing Office, National Academy of Sciences—National Research Council, Washington 25, D. C.).

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¹³ A. S. Davydov and G. F. Filippov, *Nucl. Phys.* **8**, 237 (1958).

¹⁴ C. A. Mallmann and A. K. Kerman, *Nucl. Phys.* **16**, 105 (1960).

¹⁵ C. A. Mallmann, *Nucl. Phys.* **24**, 535 (1961).

¹⁶ A. S. Davydov and A. A. Chaban, *Nucl. Phys.* **20**, 499 (1960).

¹⁷ C. J. Gallagher, Jr., and S. A. Moszkowski, *Phys. Rev.* **111**, 1282 (1958).

¹⁸ B. R. Mottelson and S. G. Nilsson, *Kgl. Danske Videnskab. Selskab, Mat. Fys. Skrifter* **1**, No. 8 (1959).

¹⁹ G. Scharff-Goldhaber, K. Takahashi, and M. McKeown, in *Proceedings of the International Congress of Nuclear Physics*, Paris, July 1964 (unpublished).