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Decay of Ir^{192}†

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A study has been made of the gamma radiation following the decay of Ir^{192}. The energies, intensities, internal conversion coefficients and multipolarities of the gamma transitions have been determined. Energy level schemes for the daughter nuclei, Pt^{192} and Os^{192}, are proposed. The spins and parities of most of the levels are given.

Iridium–192 decays by beta emission to Pt^{192}, and by orbital electron capture to Os^{192}. The gamma rays which accompany the decay have been studied by several previous investigators.[1–3] The positions of the energy levels in Pt^{192} have been rather well established. There are, however, some uncertainties in the level arrangement of Os^{192}. Previous investigations have given multipolarities of only a very few of the gamma rays, and spins of only two Pt^{192} levels. To extend this information, the present reinvestigation of the levels of Pt^{192} and Os^{192}, by means of beta and gamma spectroscopy, has been undertaken.

The equipment used in this study included a curved-crystal diffraction gamma spectrometer,[4,5] a uniform field, ring-focusing beta spectrometer,[6,7] and a coincidence system using scintillation counters.

SOURCE PREPARATION

Iridium metal foil was irradiated for 14 days in the Materials Testing Reactor in Idaho Falls, Idaho. A piece of this foil, 0.46×0.044×0.005 cm, sealed in fused quartz, was used as a source for the gamma spectrometer. Internal conversion electron sources were prepared by evaporating iridium metal on a thin mica backing. Small disks, 1 and 1.5 mm in diameter, were then punched from the mica, and a thin layer of aluminum was evaporated on the mica disk to prevent accumulation of charge. Momentum resolutions of 0.25 and 0.35% were obtained with these two sources. The external conversion electron source consisted of a small piece of iridium metal (~0.05 mm, roughly cubic), contained in 0.4 mm of copper and 0.25 mm of aluminum. The photoconverter was uranium, 1.2 mg/cm^2 thick and 3 mm in diameter. A momentum resolution of 0.65% was obtained with this source.

RESULTS

Energies and Intensities of Gamma Rays

The experimental results of measurements on the gamma rays are summarized in Table I. The energies of the gamma rays, except for the three lines at 785, 885, and 1060 kev, were measured with the curved crystal gamma spectrometer. The K-conversion line of the 885-kev gamma ray was observed with the beta spectrometer. The 785- and 1060-kev lines were observed only with the scintillation counters.

The half-width of lines observed in the gamma spectrometer was 0.25 mA. The errors in the energies, which are shown in Table I, correspond to 1/20 of this line width, except for the weak 283.35, 374.7, and 416.6-kev lines where the assigned error corresponds to $\frac{1}{5}$ of the line width. The error given for the 885-kev line is $\frac{1}{2}$ the line width in the beta spectrometer, while the error given for the two lines observed only by scintillation counter is ±3%. The energy measurements agree well with those reported previously.[1–3]

The gamma intensities shown in Table I are based primarily on measurements of external conversion electrons in the beta spectrometer. Corrections to the intensities were made for gamma absorption in the source container, the energy and angular dependence of the photoelectric ejection from the uranium converter, and the transmission of the Geiger counter window. Auxiliary checks on the gamma intensities were made with the gamma spectrometer and the scintillation counters. The accuracy of the intensity measurements is estimated to be ±20% for lines with a relative intensity greater than 2 (Table I), and 50% for the weaker lines.

Assignment to either the Pt or the Os branch of the decay was assured by comparing the energies of the gamma rays, as determined by gamma spectrometer measurements, with the energies of the K-conversion lines, as measured with the beta spectrometer. Isotope assignments for all except four of the seventeen gamma rays listed in Table I were made in this manner. The 885-kev line was assigned to Pt because it was observed to be in coincidence with one of the 300-kev lines (296, 308 or 316 kev) of Pt. The three gamma rays

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[3] M. W. Johns and S. V. Nablo, Phys. Rev. **96**, 1599 (1954).

[4] J. W. M. DuMond, *Beta- and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (North-Holland Publishing Company, Amsterdam, 1955) ,Chapter 4.

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at 374.7, 785, and 1060 kev could not be definitely assigned by the above methods. They were tentatively fitted into the decay scheme according to their energy.

Internal Conversion Coefficients and Multipolarities

Relative intensities of the internal conversion electron lines, I_e, were obtained with the beta spectrometer. These, together with the gamma intensities, I_γ, of Table I, determine the internal conversion coefficients according to $\alpha = kI_e/I_\gamma$, in which k is a constant for all transitions. The constant k was fixed by assuming the theoretical value for α_K of the 316-kev transition. The multipolarity of this transition was known unambiguously to be $E2$ from the K/L conversion ratio and the $(L_{\mathrm{I}}+L_{\mathrm{II}})/L_{\mathrm{III}}$ ratio, as shown in Table II. From these ratios, the maximum possible $M1$ admixture must be less than 1%. Moreover, from the decay scheme derived from the energy and intensity data (Fig. 1) it is most probable that the 316-kev transition goes to the zero-spin ground state, excluding any mixed multipoles.

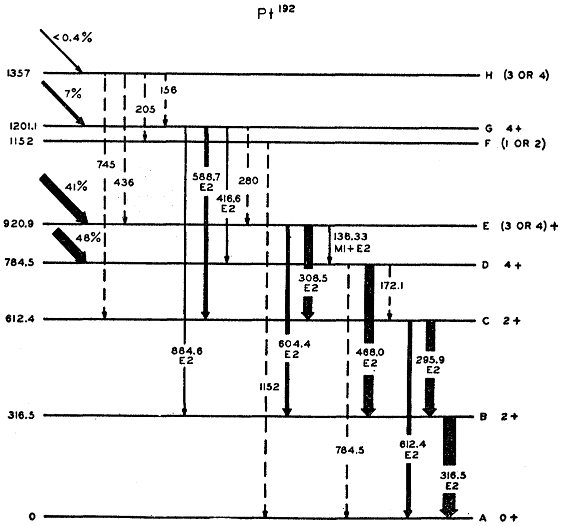

FIG. 1. Proposed decay scheme for Pt^{192}. Relative intensities of the transitions are indicated by the weight of the lines. (Dotted lines have not been observed in this laboratory.) Spins in parentheses are uncertain.

The multipolarities in Table I were assigned by comparing the experimentally determined conversion coefficients with the theoretical values.[8] All transitions turned out to be $E2$ or $E2+M1$, indicating the same parity for all levels.

Energy Levels

The total intensity of the gamma radiation into and out of the various levels shown in Fig. 1 indicate the presence of four beta groups, with relative intensities 48 : 41 : 7 : <0.5, feeding levels D, E, G, and H, respectively. The end point of the most energetic group was measured as 673±10 kev, in good agreement with previous measurements.[3,9] The corresponding Ir^{192} − Pt^{192} mass difference is 1457±10 kev. From the relative intensities and energies of these beta groups, the calculated values[10] of log ft are 8.3, 8.1, 8.1, >8.1, for the transitions to levels D, E, G and H, indicating first forbidden transitions.

TABLE I. Data relative to gamma transitions following the decay of Ir^{192}.

Element	Gamma energy E_γ	Gamma intensity I_γ[d]	Experimental conversion coefficients α_K	$\alpha_{L_{\mathrm{I}}+L_{\mathrm{II}}}$	$\alpha_{L_{\mathrm{III}}}$	Multi-polarity
Pt	136.33 ±0.02	0.19	1.0	0.63	0.44	$E2$
Os	201.31 ±0.04	0.46	0.30	0.12	0.07	$E2+M1$
Os	205.75 ±0.04	3.9	0.16	0.077	0.04	$E2$
Os	283.35 ±0.20	0.6	0.04	···	···	($E2$)
Pt	295.94 ±0.09	36	0.065	0.025	0.006	$E2$
Pt	308.45 ±0.09	35	0.069	0.028	0.008	$E2$
Pt	316.46 ±0.09	100	0.054[e]	0.018	0.006	$E2$
(Os)[a]	374.7 ±0.5	1.9	···	···	···	···
Pt	416.6 ±0.7	1.6	0.019	···	···	($E2$)
Pt	467.98 ±0.22	64	0.022	0.0052	0.001	$E2$
Os	484.75 ±0.23	3.9	0.022	···	···	$E2$
Pt	588.4 ±0.6	7.1	0.011	0.0031	···	$E2$
Pt	604.5 ±0.9	14	0.016	0.0031	···	$E2(+M$ 1
Pt	612.9 ±0.9	8.4	0.011	0.0023	···	$E2$
(Pt)[b]	785 ±20	0.1	···	···	···	···
Pt[c]	885 ±2	0.5	0.007	···	···	($E2$)
(Os)[b]	1060 ±30	0.05	···	···	···	···

[a] 374.7-kev line observed only with the gamma spectrometer. Its K-conversion line falls between the 308.45- and 316.46-kev L lines.
[b] Observed only by scintillation counter.
[c] Observed in beta spectrometer and scintillation counters.
[d] All intensities are *relative* intensities.
[e] α_K of the 316.46-kev line was assumed to have the theoretical value for an $E2$ transition. See text.

Pt^{192} is an even-even nucleus, and it is assumed that the spin of its ground state is 0. Levels B and C both decay to the ground state by $E2$ transitions—consequently the spins of both levels must be 2. The 2+ − 2+ transition (CB) has less than 5% $M1$ admixture. It is interesting to note that the intensities of the transitions CA and CB follow the general pattern found in the heavy even-even nuclei.[11]

The spin of level D was determined by the angular correlation of the 316- and 467-kev lines, and the spin of level G, by the angular correlation of the 588- and 613-kev lines. Two $E2$ transitions connect the three levels D, B, A (or G, C, A), having spins J, 2, 0, where J might have any value from 0 to 4. Theoretical

TABLE II. Experimental and theoretical conversion ratios for 316-kev transition.

		Theor.			
	Exper.	$E1$	$E2$	$M1$	$M2$
K/L	2.3	5.0	2.3	6.5	4.6
$(L_{\mathrm{I}}+L_{\mathrm{II}})/L_{\mathrm{III}}$	3.0	8.1	3.8	220	17

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[8] M. E. Rose, *Beta- and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (North-Holland Publishing Company, Amsterdam, 1955), Chap. 14, and private communication.

[9] P. W. Levy, Phys. Rev. 72, 352 (1947).

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[11] Goldhaber and Weneser, Phys. Rev. 98, 212 (1955).

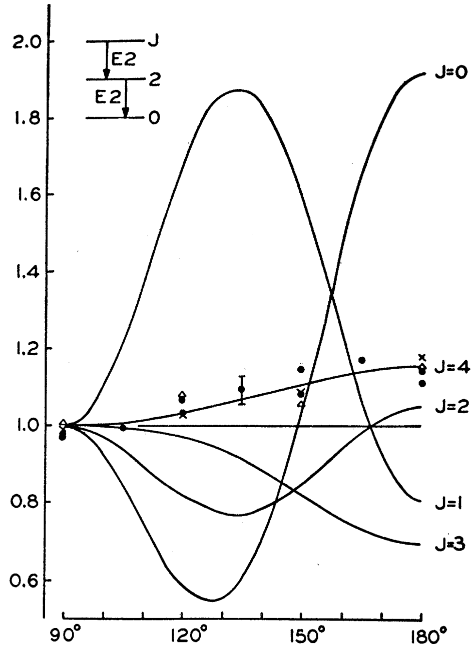

FIG. 2. Angular correlation of the 316- and 467-kev gamma rays. The curves are the theoretical correlation functions for two quadrupole transitions between states having spins J, 2, 0. They have been corrected for the size of the detector, according to the method due to M. E. Rose [Phys. Rev. **91**, 610 (1955)]. Three sources were used, indicated by the marks ● (metallic Ir evaporated on mica), × (IrCl$_3$ dissolved in HCl), △ (IrCl$_6^=$ complex in a precipitate).

angular correlation curves[12] for the five possible cases were compared with the observed angular correlation (Fig. 2). The best fit was obtained for $J=4$, in both instances.[13]

As indicated above, two strong beta groups feed the 4+ levels, D and G, and are first forbidden. Therefore, the parity of the Ir^{192} ground state must be odd, and the spin must have a value between 2 and 6. If the spin were 2, 3, or 4, transitions to levels B and C (which are 2+ levels) would also be first forbidden. The absence of such transitions suggests strongly that the spin of the Ir^{192} nucleus must be 5 or 6. Nordheim's composition rules[14] (which exclude the spin change $\Delta I=\pm 1$) lend weight to the choice of 6 for the spin of Ir^{192}. However, this does not seem strong enough to eliminate completely the possibility of a 5 assignment. We therefore assign the Ir^{192} ground state (5 or 6)−.

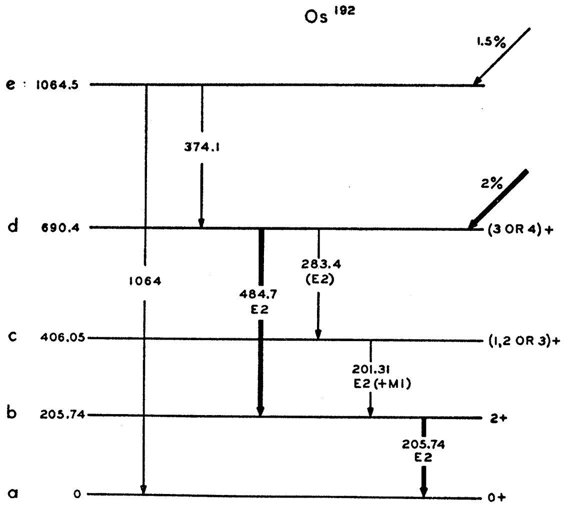

FIG. 3. Proposed decay scheme for Os^{192}. Relative intensities of the transitions are indicated by the weight of the lines. Spins in parentheses are uncertain.

The uncertainty in the spin of Ir^{192} leads to a corresponding uncertainty in the spin of level E in Pt^{192}. The $E2$ transition to level C limits this spin to 4 or less. The first forbidden beta transition indicates a spin not less than 3. The assignment, therefore, is (3 or 4)+.

Levels F and H are included in the decay scheme entirely on the basis of results reported by other investigators, and consequently, conclusions drawn about the spin and parity of these levels are more tentative. Some arguments, however, can be given. A beta transition to level F, if it exists, must be at least second forbidden ($\log ft > 10.5$). The spin of this level, therefore, must be 4 or less. Since the major evidence for the existence of this level is a gamma transition to the ground state, the spin of F is probably 1 or 2. A similar argument suggests a spin of 3 or 4 for level H.

Figure 3 gives a tentative decay scheme for the Os^{192} branch. This scheme differs from that which has been published earlier.[1,3] These earlier versions place the first excited level at 283 kev. Coulomb excitation of natural Os[15,16] has revealed two deexcitation peaks, one at 155 kev (due to Os^{188})[17] and a broad one at 200 kev. There was no evidence for a peak at 283 kev. It seems more likely, therefore, that either the 201- or the 205-kev line is the ground-state transition. According to the conversion data (Table I) the 205-kev line appears to be a pure $E2$ transition, while the 201-kev line seems to have ~20% $M1$ admixture and therefore cannot be a ground state transition. The order of the 201- and 283-kev transitions in Fig. 3 cannot be decided with the available data.

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[12] H. Frauenfelder, *Beta- and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (North-Holland Publishing Company, Amsterdam, 1955), Chap. 19.

[13] *Note added in proof.*—Taylor and Pringle have recently reported investigations of the angular correlation of gamma rays in Pt^{192} [Phys. Rev. **99**, 1345 (1955)]. Their experimental results agree well with those reported here. They give two alternative interpretations of their measurements. (1) Level D has spin 3, and the 468-kev transition is mostly dipole (94% $M1$ and 6% $E2$). (2) Level D has spin 4, and the 468-kev transition is quadrupole. Our measurements of the internal conversion coefficients (see Table I) are consistent with only the second alternative.

[14] L. W. Nordheim, Revs. Modern Phys. **23**, 322 (1951).

[15] N. P. Heydenburg and G. M. Temmer, Phys. Rev. **93**, 906 (1954).

[16] N. P. Heydenburg (private communication).

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If the decay scheme suggested in Fig. 3 is indeed the correct one, some striking similarities can be noted between the two branches of the decay. The ratio of the energy of the second excited state to that of the first in Os^{192} is 1.98, while the corresponding ratio in Pt^{192} is 1.94. The ratio of intensities of the transitions among the lowest four levels is remarkably similar in the two branches. As in Pt, the parities of the first four Os levels are all positive. The spin of level *b* is 2. The spin of level *c* can be limited to (1, 2, or 3), and that of level *d* to (3 or 4). This is consistent with the spin assignments made in the Pt branch.

The intensities of the gamma rays indicate that ~3.5% of the Ir^{192} decays go by electron capture to Os^{192}. These transitions lead to levels *d* and *e*, with the relative intensities 2:1.5. An upper limit of 10^{-6} positrons per decay can be put on the intensity of positron emission, from a search for a positron spectrum. From this, the energy of the transition of level *d* must be less than 1.3 Mev, with a corresponding upper limit of 2 Mev for the $Ir^{192}-Os^{192}$ mass difference.

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First Excited State of Mn^{55}†

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The spin of the first excited state of Mn^{55} at 128 kev has been measured in the electric excitation process with 3-Mev alpha particles. Determinations of the *K* conversion coefficient and the angular distribution of the gamma rays lead to a spin assignment of $7/2^-$ for the excited state and multipolarity *M*1 for the transition to the ground state. The *K* conversion coefficient ($\alpha_K = 0.0144 \pm 0.003$) was measured by comparison with the known coefficient of the 137-kev transition in Ta^{181}. The spin, parity, and transition probability are consistent with those expected for a rotational state.

INTRODUCTION

THE first excited state of Mn^{55} at 128 kev has been observed in the reactions[1–3] $Mn^{55}(p,p')Mn^{55*}$ and $Mn^{55}(n,n')Mn^{55*}$ and in electric excitation.[4] Electric excitation, which has been shown to be *E*2, and multipolarity of the decay, shown below to be *M*1, show that the level has negative parity, since the ground state is $5/2^-$. Since the nature of the level is not known, it is of interest to determine whether the spin, as well as the parity, is consistent with the rotational prediction[5] of 7/2. We have measured the *K* conversion coefficient and the angular distribution of the gamma rays following electric excitation of this level in order to determine the spin. Alpha particles from the Duke 4-Mev Van de Graaff accelerator were used as the bombarding particles.

CONVERSION COEFFICIENT

In this case, where both *M*1 and *E*2 decay are allowed, the analysis of the angular distribution of the gamma rays is unique only if one can determine the multipolarity of the transition by other means. This can be done, of course, from conversion measurements. For low-energy transitions in light elements, the *K* conversion coefficient is much more sensitive to multipolarity than the *K/L* ratio. We have measured the *K* conversion coefficient by comparing the number of *K* electrons and gamma rays of the 128-kev transition from a thin Mn target with those of the 137-kev transition from a thin Ta target. Since the *K* conversion coefficient for the latter transition is known, one can determine the coefficient for the Mn transition. The targets were made by vacuum evaporation. The Mn was evaporated on a thick carbon backing, while the Ta was evaporated on a thick copper backing. The electrons were measured using a wedge-shaped magnetic beta-ray spectrometer.[6] The gamma rays from the same targets were detected with a NaI crystal mounted on a Dumont 6292 phototube. Since the two gamma rays are of essentially the same energy, no correction was necessary for absorption or crystal efficiency.

The results of the conversion measurements are as follows: the ratio of Ta *K* electrons to Mn *K* electrons is 4.9 ± 0.5 and the ratio of Ta gamma rays to Mn gamma rays is 0.039 ± 0.004. These individual ratios depend, of course, on the target thicknesses. From these data one concludes that the ratio of $\alpha_K(\text{Ta})$ to $\alpha_K(\text{Mn})$

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