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Decay of 10.2-day ^{188}Pt

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The decay properties of ^{188}Pt were investigated with the use of mass-separated sources. Singles and coincidence measurements were made by using x- and γ-ray Ge(Li) detectors as well as a Si(Li) electron detector. These results were combined with previously available conversion-electron data which had been obtained with a magnetic spectrometer. From this information a level scheme was constructed for ^{188}Ir. A tentatively proposed level at 317 keV was eliminated on the basis of our results. In addition, several transitions attributed to ^{188}Pt decay were not observed in the present study. α particle and γ-ray spectra were also measured with the detectors positioned in calibrated geometries. The α-decay energy and branching ratio of ^{188}Pt were determined to be 3915 ± 10 keV and $(2.8 \pm 0.5) \times 10^{-7}$, respectively.

[RADIOACTIVITY ^{188}Pt, measured E_γ, I_γ, $\gamma\gamma$ coin, $e\gamma$ coin, E_α, I_α; ^{188}Ir deduced levels, J^π; ^{188}Pt deduced α-decay branching ratio. Mass-separated sources.]

I. INTRODUCTION

Both the electron-capture and α-particle decay modes of ^{188}Pt have been investigated.[1-6] As of the present time, two disagreements have not been resolved. First, Plajner *et al.*[1] reported several transitions in ^{188}Ir which had not been observed previously.[2,3] Second, large discrepancies exist between the two sets of values reported[4,5] for the ^{188}Pt α-decay energy and branching ratio.

An extensive program designed to investigate the decay properties of neutron-deficient nuclei in the region of $Z \leq 82$ has been in progress at the isotope separator facility on-line with the Oak Ridge isochronous cyclotron. During two experiments involving the production of thallium isotopes in ^{14}N+^{180}W reactions, we collected samples of $A = 188$ off-line at the focal plane of the separator. After the decay of the short-lived ^{188}Tl, ^{188}Hg, and ^{188}Au, we had sources of 10.2-*d* ^{188}Pt in equilibrium with its 41.5-*h* daughter ^{188}Ir. The electron-capture decay of ^{188}Pt was then investigated by using x-ray germanium, γ-ray Ge(Li), and electron Si(Li) detectors. Singles and coincidence measurements were made. The coincidence data were taken in a three-word list mode, i.e., γ-γ-τ and e-γ-τ, with an analog-to-digital converter interfaced to a computer-based acquisition system. The α decay of ^{188}Pt was studied with Si(Au) α particle and Ge(Li) γ-ray detectors whose absolute efficiencies had been determined by using calibrated standard sources.

II. ELECTRON-CAPTURE DECAY OF ^{188}Pt

Table I lists the ^{188}Ir photon energies and intensities measured in the present work. These data are compared in the table with γ-ray intensities from Refs. 1 and 3 and transition energies, except where noted otherwise, of Prospero,[2] who used a magnetic spectrometer to study the conversion-electron spectrum. Multipolarities given in Table I are based on his subshell conversion-electron data and on the ratio of electron (again from Ref. 2) to γ-ray (present data) intensities, assuming that the 187.6-keV transition is pure $M1$. Our coincidence results are summarized in Table II.

The ^{188}Pt decay scheme, based on the data in Tables I and II, is shown in Fig. 1. (Half-lives indicated for the ^{188}Ir excited states are from Ref. 6.) The 317.0-keV tentative level proposed in Ref. 1 is eliminated because the 36.8- and 129.0-keV transitions reported by Plajner *et al.*[1] to deexcite this level were not observed in either singles or coincidence spectra. The 280.3-keV level is now considered tentative because only the existence of the 280.3-keV transition could be confirmed. Other transitions proposed to deexcite the level were 225.0 and 92.9 keV. The first of these was not seen, while the intensity measured for the 92.9-keV γ ray is substantially less than the value given in Ref. 1. Prospero[2] observed an electron peak which could have been either the L_{III} line of the 132.9-keV transition or the K line of a possible 197.8-keV transition (see Table I). Some in-

TABLE I. Energies, intensities, and multipolarities of transitions in ^{188}Ir.

E_γ		I_γ (rel.)			
Previous work[a]	Present work	Present work	Ref. 3	Ref. 1	Multipolarity[b]
	K x ray	5060 (500)	5200 (780)	4860 (500)	
36.8 (10)[c]	···	<1	···	~3	
41.94 (5)	41.98 (5)	27 (3)	21 (11)	29 (5)	$M1+E2$ ($\delta^2=0.007$)
54.76 (5)	54.85 (5)	39 (4)	16 (8)	42 (5)	$M1+E2$ ($\delta^2=0.6$)
92.5 (10)[c]	92.9 (2)?	~1.2	···	~2.5	
96.68 (7)	96.70 (5)	8.8 (35)	10 } 31 (5)	} 26 (3)	$M1+E2$ ($\delta^2=1.8$)
98.38 (5)	98.37 (5)	17.5 (17)	21 }	}	$M1$
129.0 (5)[c]	···	<1	···	~2	
132.88 (7)	132.86 (10)	13.0 (26)	16 (3)	12.0 (12)	$E2$
140.31 (5)	140.35 (10)	120 (6)	115 (17)	120 (12)	$M1$
166.5 (20)[c]	···			~1.5	
187.64 (5)	187.59 (10)	1000 (50)	1000 (150)	1000 (100)	$M1$
195.13 (5)	195.05 (10)	960 (50)	958 (144)	960 (100)	$M1$
197.78 (7)?	197.8 (4)?	<3	···	···	$E1$[d]
225.0 (20)[c]	···	<2	···	~2.5	
280.54 (4)	280.30 (15)	16 (2)	11 (2)	13 (3)	$E2$
283.0 (4)[e]	283.15 (20)	5.4 (27)	5.7 (9)	7 (2)	$E1$[d]
290.6 (6)[e]	290.64 (20)	5.5 (20)	5.7 (9)	6.0 (6)	$E1$[d]
381.60 (5)	381.43 (10)	385 (20)	365 (55)	385 (40)	$E1$
423.58 (7)	423.34 (10)	225 (12)	229 (34)	230 (23)	$E1$
478.3	478.3 (5)	92 (15)	99 (15)	80 (10)	$E1$
573[c]				~0.5	

[a] From Ref. 2, except where noted.
[b] From conversion electron data in Ref. 2 and γ intensities from present work.
[c] Energy from Ref. 1.
[d] From level scheme.
[e] Energy from Refs. 1 and 3.

TABLE II. $\gamma\gamma$ and γce coincidence results. The letter Y indicates coincidences observed.

E_γ \ Gate	41.98	54.85	K_{α_1} x ray	132.86	140.35	187.59	195.05	280.30	381.43
(36.8)									
41.98		Y	Y						Y
54.85	Y		Y	Y	Y				Y
K x rays	Y	Y	Y	Y	Y	Y	Y	Y	Y
92.9?			?	?		?			
96.70			Y						
98.37	Y	Y	Y						
(129.0)									
132.86		Y	Y						
140.35		Y	Y						
(166.5)									
187.59			Y						
195.05			Y						
197.8?			?						
(225.0)									
280.30			Y						
283.15	Y		Y		?		Y		
290.64			Y	?		Y			
381.43	Y	Y	Y						
423.34		Y							
478.3									

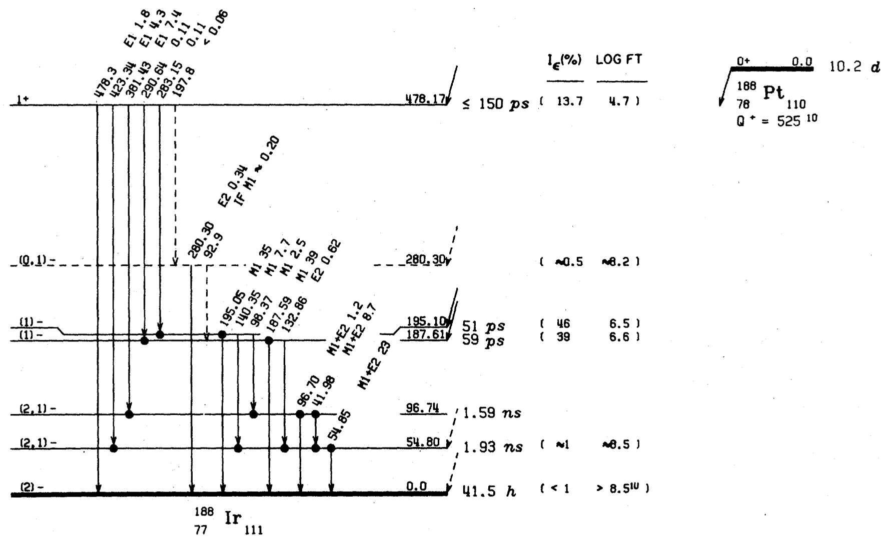

FIG. 1. Decay scheme of ^{188}Pt. Dots indicate observed coincidences. Dashed lines indicate uncertain transitions. Numbers following γ-ray energies represent total transition intensities per 100 ^{188}Pt electron-capture decays. They are calculated from photon intensities and theoretical conversion coefficients.

dication of a peak at 197.8 keV was seen in our γ-ray spectrum. For that reason, we show it as possibly deexciting the 478.2-keV level. It should be pointed out that the K-line intensity of the possible 197.8-keV γ ray is expected (assuming it is $E1$) to be less than 3% of the peak assigned to the L_{III} line of the 132.9-keV transition. The 478.3-keV γ ray is obscured in the spectrum by the strong 478.0-keV transition of the daughter ^{188}Ir decay. The 478.3-keV intensity given in Table I was obtained from the spectrum taken in coincidence with iridium L x rays and by comparing it with the intensity of the 423.3-keV γ ray. (The contribution due to the coincidence with the L x rays from L conversion of the 54.85-keV transition was taken into account in the calculations.) Finally, the 573-keV transition seen in Ref. 1 cannot belong to the decay of ^{188}Pt because of the nuclide's electron-capture Q value.

Total transition intensities were calculated from our γ-ray intensities and theoretical[7] conversion coefficients. The absolute intensities shown in Fig. 1 were obtained by requiring the sum of all transition intensities to the ground state to be 100%. Electron-capture decay to the ground state, if any, should be less than 1%, since the $\log f_1 t$ value must be greater than 8.5 for a first-forbidden unique transition. Shown in Table I are relative photon intensities normalized to a value of 1000 for the 187.6-keV γ ray; to obtain absolute photon intensities per 100 decays, they should be multiplied by 0.0189 ± 0.0007. Feedings to the excited states were calculated from the intensity imbalance at each level.

The $\log ft$ value of 4.7 establishes the 478.2-keV level to be 1^+. The ground-state parity is negative because the 478.3-keV transition is $E1$ in character; its spin is most probably 2 from $\log ft$ values for the ^{188}Ir capture decay to $2^+, 3^+$ levels in ^{188}Os.[8,9] The remainder of the level assignments shown in Fig. 1 are based on these two spins and parities and on the transition multipolarities.

Capture ratios for the 187.6-, 195.1-, and 478.2-keV levels, determined from our coincidence data, are listed in Table III. Theoretical values[10] and the results of Hanson *et al.*[3] are also included in the table. The K to total capture (ϵ_K/ϵ) ratios for the first two levels were calculated from K x rays observed in coincidence with the K conversion-electron lines of the 187.6- and 195.1-keV transitions. Specifically, they were deduced from the intensities of the K x rays and

TABLE III. Capture ratios for the 188-, 195-, and 478-keV levels.

	Present work	Ref. 3	Theory $Q^+ = 525 \pm 10$	$Q^+ = 535 \pm 10$	$Q^+ = 550 \pm 10$
ϵ_K/ϵ (187 level)	0.747 (15)	0.766 (23)	0.748 (3)	0.751 (3)	0.755 (3)
ϵ_K/ϵ (195 level)	0.740 (15)	0.744 (20)	0.746 (3)	0.749 (3)	0.753 (3)
ϵ_K/ϵ (478 level)	<0.003	≤0.01	0	0	0.00 (3)
ϵ_L/ϵ (478 level)	0.67	···	0.65 (5)	0.68 (3)	0.698 (13)

their sum peaks by applying a well-known technique (see, e.g., Ref. 11). Hanson *et al.*[3] calculated ϵ_K/ϵ from the ratio of the K x-ray intensities seen in coincidence with K and L conversion electrons. The two sets of experimental numbers are in agreement with the theoretical ratios. Our ϵ_K/ϵ value for the 187.6-keV level, however, agrees somewhat better with theory.

For the 478.2-keV level, ϵ_L/ϵ was determined from the γ-ray spectrum seen in coincidence with L x rays. The 423.3-keV γ ray did not appear in the spectrum coincident with K x rays. The limit for ϵ_K/ϵ given in Table III was deduced from a comparison of the 187.6- and 195.1-keV γ-ray intensities in that same spectrum with the upper limit which could be set for the number of 423.3-keV counts. The same method was used by Hanson *et al.*[3]; the two experimental limits are in agreement.

It can be seen from Table III that the experimental ϵ_K/ϵ and ϵ_L/ϵ ratios agree with the theory for electron-capture decay energies in the range of 515 – 560 keV. The best overall agreement is obtained for 525 ± 10 keV. With this Q value we calculated the expected K x-ray intensity to be 99 ± 3 per hundred capture decays [$\omega_K = 0.962 \pm 0.018$ (Ref. 12) was used]. This compares well with our measured value (Table I) of 96 ± 10.

Systematics of odd-mass iridium isotopes and $N = 109$, 111 isotones indicate either a $\{p\frac{3}{2}[402] + n\frac{1}{2}[510]\}$ or a $\{p\frac{3}{2}[402] - n\frac{7}{2}[503]\}$ configuration for the ^{188}Ir ground state. The same structures have been suggested in Refs. 8 and 13. Malmskog and Berg,[6] however, proposed that the ground and first-excited states could be members of an anomalous $K = 1$ rotational band with either $\{p\frac{1}{2}[400] + n\frac{1}{2}[510]\}$ or $\{p\frac{1}{2}[400] + n\frac{1}{2}[521]\}$ configurations. They based this proposal on the fact that the $E2$ component of the 54.85-keV transition is enhanced. On the other hand, the 132.9-keV $E2$ transition and the $E2$ component of the 96.7-keV transition are also enhanced.[6] It is possible then that all three of these enhancements could instead be due to Coriolis interactions. Strong mixings are in fact expected between $\frac{1}{2}[510]$ and $\frac{3}{2}[512]$ neutron states as well as between $\frac{3}{2}[402]$ and $\frac{1}{2}[400]$ proton states. Thus if levels connected by the three transitions have these components in their structure, one will have a more plausible explanation for the observed enhancements.

In Ref. 3 a $\{p\frac{11}{2}[505] - n\frac{9}{2}[505]\}$ configuration was suggested for the 478.2-keV level. If the main components of the low-lying levels are composed of the states mentioned above, any transitions between them and the 478.2-keV level will then be forbidden. However, the Weisskopf hindrance factors[6] for the $E1$ transitions deexciting this level are not unusually large, so that the configuration proposed[3] for it is not likely.

More definitive structure information is needed before a meaningful interpretation can be made for the ^{188}Ir levels. Spectroscopic data via reaction studies would be helpful. Two possible reactions are (d,n) and $(^3\text{He},d)$ induced on ^{187}Os. In addition, a measurement of the ground-state magnetic moment would provide a valuable clue as to its structure.

III. α-PARTICLE DECAY OF ^{188}Pt

As mentioned in the introductory section, absolute efficiencies were determined for the α particle and γ-ray detectors used in our α-decay study. The number of electron-capture disintegrations was deduced from the intensities of the 187.6- and 195.1-keV γ rays and the decay scheme shown in Fig. 1. From this value and the number of α-particle events observed, the ^{188}Pt α/total branching ratio was found to be $(2.8 \pm 0.5) \times 10^{-7}$. An α-decay energy of 3915 ± 10 keV was measured by using a precision pulser and ^{148}Gd (3183 keV) and ^{240}Pu (5168 keV) as calibration standards. These data are summarized in Table IV where they are compared with the results of Graeffe[4] and Karras *et al.*[5] It is seen that the present measurements support the data reported in Ref. 4.

The first-excited 2^+ state in ^{184}Os is at 120 keV. We examined the α-particle spectrum for a group corresponding to α decay to this state. (Fine-structure decay has been observed[14] for ^{176}Pt and ^{178}Pt with ground/first-excited intensity ratios of 36 and 70, respectively.) However, because of

TABLE IV. α-decay properties of ^{188}Pt.

	Present study	Ref. 4	Ref. 5
E_α (keV)	3915 ± 10	3930 ± 10	3870 ± 50
α/total	$(2.8 \pm 0.5) \times 10^{-7}$	$(3.0 \pm 0.6) \times 10^{-7}$	$\sim 5.0 \times 10^{-7}$

TABLE V. α-decay reduced widths (δ^2) for even-A platinum isotopes.

Isotope	E_α (MeV)	Partial α half-life (sec)	Reduced width (MeV)
^{174}Pt	6.035	0.81	0.177
^{176}Pt	5.750	14.3	0.159
^{178}Pt	5.457	264	0.173
^{180}Pt	5.14	$(1.67\times10^{4})^{a}$	0.096
^{182}Pt	4.84	$(7.14\times10^{5})^{a}$	0.090
^{184}Pt	4.50	$(6.64\times10^{7})^{a}$	0.103
^{186}Pt	4.23	$(5.33\times10^{9})^{a}$	0.077
^{188}Pt	3.915[b]	$(3.15\times10^{12})^{b}$	0.027
^{188}Pt	3.93[c]	$(2.94\times10^{12})^{c}$	0.022
^{188}Pt	3.87[d]	$(1.76\times10^{12})^{d}$	0.111
^{190}Pt	3.18[c]	$(1.70\times10^{19})^{c}$	0.030
^{190}Pt	3.11[e]	$(2.18\times10^{19})^{e}$	0.137

[a] Half-life deduced from an estimated rather than a measured α branch.
[b] Present work.
[c] Reference 4.
[d] Reference 5.
[e] Reference 17.

the small branching ratio, the counting rate was extremely low; only 100 events were recorded in the main α group. Thus, while scattered counts were seen at about 120 keV below the 3915-keV peak, one could not say with certainty that the fine-structure decay was observed. If decay to the 2^+ state exists, its branch is <5% that of the decay to the ^{184}Os ground state.

Relative decay probabilities can be determined with the use of an α-decay-rate theory which removes the dependence on energy and on atomic and mass numbers. One convenient formalism has been developed by Rasmussen.[15] In it a reduced width, δ^2, is defined by the equation, $\lambda=\delta^2P/h$. Here λ is the decay constant, h is Planck's constant, and P is the penetrability factor for the α-particle to tunnel through a barrier.

α transitions between ground states of doubly even nuclei (s-wave transitions) are considered to be unhindered. Their reduced widths are therefore taken to represent the norm. Hindrance factors for other types of transitions in neighboring nuclei are then obtained by comparing their reduced widths with those of the s-wave decays. The latter reduced widths vary in a regular manner with neutron and proton numbers. Typically, they peak at a few mass numbers beyond closed shells and then decrease in value as one approaches the next shell (see Ref. 14 for a discussion of this point).

In Table V we have listed reduced widths for the even-A platinum α emitters. They are based on decay energies, half-lives, and α branches summarized in a recent compilation.[16] For ^{188}Pt and ^{190}Pt more than one set of values are given because of discrepancies. One can note from Table V that as the $N=126$ shell is approached, that is, as A becomes larger, the reduced widths decrease. The values for ^{188}Pt from our work and Ref. 4 and for ^{190}Pt (Ref. 4) follow this trend. Those of Ref. 5 for ^{188}Pt and of Ref. 17 for ^{190}Pt are much too high. One can conclude then that the α-decay energies measured in Refs. 5 and 17 for ^{188}Pt and ^{190}Pt, respectively, are too low. Also, the fact that the ^{188}Pt α branch reported in Ref. 5 is large (see Table V) contributes to the high value for the reduced width.

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