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K-Capture in the Decay of ^{191}Pt

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Abstract

Relative K-capture probabilities to three levels of ^{191}Ir are determined from the decay of ^{191}Pt using the sum coincidence method based on summing of gamma rays and K X-rays in a single HPGe detector. The results agree with theoretical values. The electron-capture decay energy calculated using β-decay properties to different levels belonging to the same rotational family is in agreement with the experimental value.

1. Introduction

The K X-ray, γ-ray sum coincidence method has been applied to a number of nuclei, which decay via electron capture (EC) to determine the relative K-capture probabilities, by several authors (Singh and Sahota 1984; Singh *et al.* 1985; Sahota *et al.* 1987, 1988; Ghumman *et al.* 1989). The radioactive decay of (69·6 hr) ^{191}Pt to the excited states of ^{191}Ir also belongs to the same class. The decay characteristics have been recently summarised by Browne (1989), but the experimental values of K-capture probabilities to various levels of ^{191}Ir are still unreported.

In the present work the relative K-capture probabilities to the 178, 351 and 538 keV levels in ^{191}Ir (with strong feeding in EC decay) are determined with the K X-ray, γ-ray sum coincidence method. These are compared with theoretical values calculated from the Behrens and Janecke (1969) method. The EC decay energy Q_{EC} calculated by the von Dincklage (1985) method using reduced transition probability ratios agrees with the experimental value from P_K ratios.

2. Experimental Method

The radioactive source of ^{191}Pt was obtained from the Bhabha Atomic Research Centre, Bombay. The source for the singles measurements was prepared by drying a drop of liquid source under an infrared lamp on a strip of perspex containing a 2 mm^2×2 mm cavity. For sum peak measurements a very weak source (~3 μCi) was prepared.

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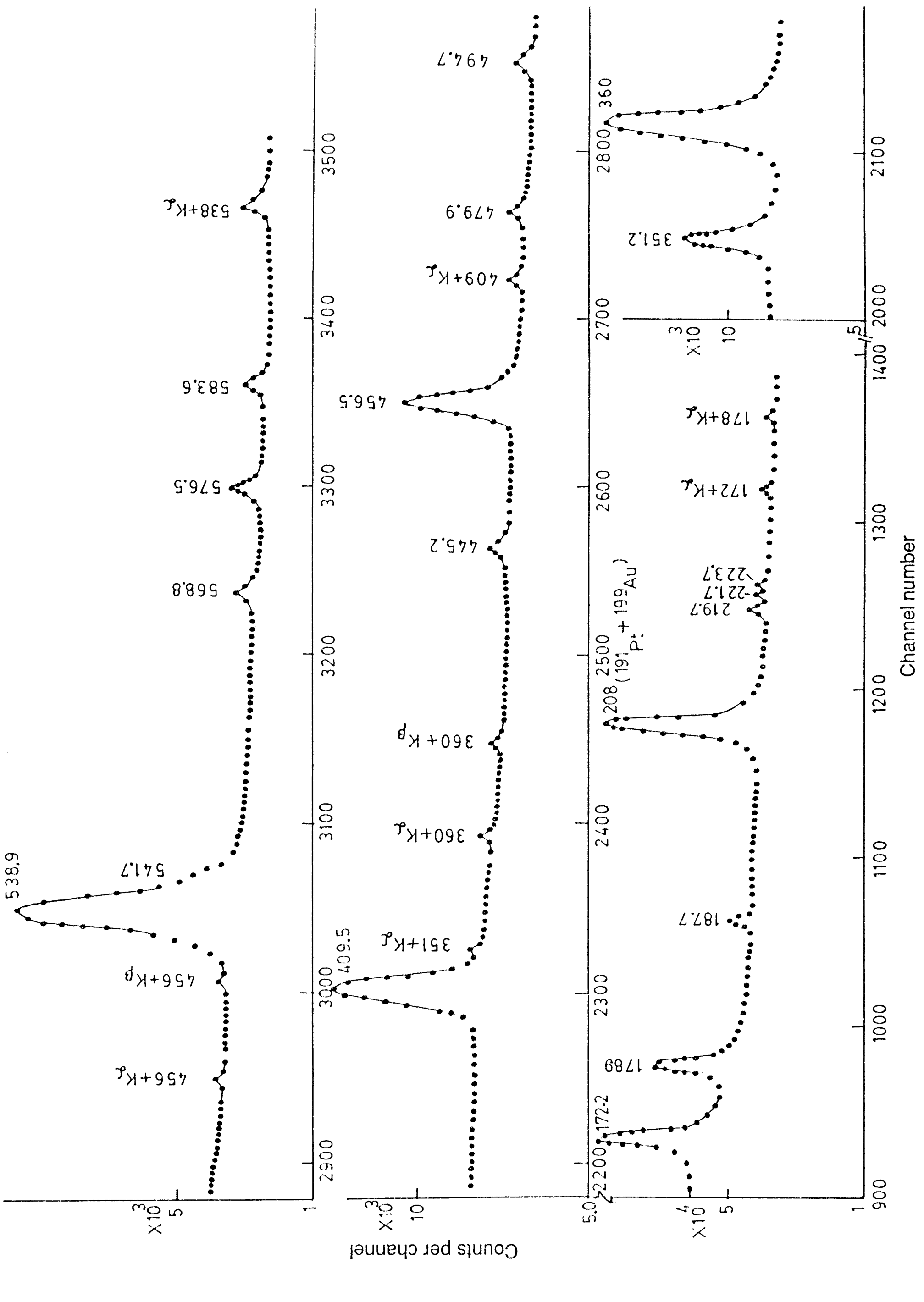

Fig. 1. Relevant portion of sum spectrum ($d = 3$ mm) in the decay of ^{191}Pt with a 120 cm^3 HPGe detector.

For relative intensity measurements the source was placed at a distance of 25 cm from the face on the axial line of the detector. [The only impurity present was due to ^{199}Au(3·14 d). Since ^{199}Au decays into ^{199}Hg(β^-) with only 158 and 208 keV γ-rays, it did not interfere in our sum peak measurements.] For sum peak measurements, the distance was reduced to 3 mm. The sum peak and singles measurements were carried out with a 120 cm^3 coaxial HPGe detector coupled with a 4K multichannel analyser. The efficiency curve for the 120 cm^3 detector was prepared using strong photopeaks from ^{152}Eu, ^{133}Ba, ^{160}Tb, ^{169}Yb and ^{182}Ta radioactive sources. Four spectra each for singles and sum coincidence measurements were taken. They were analysed separately and the final result is the weighted average of individual runs. A typical sum spectrum showing the singles and their sum peaks with K X-rays is shown in Fig. 1.

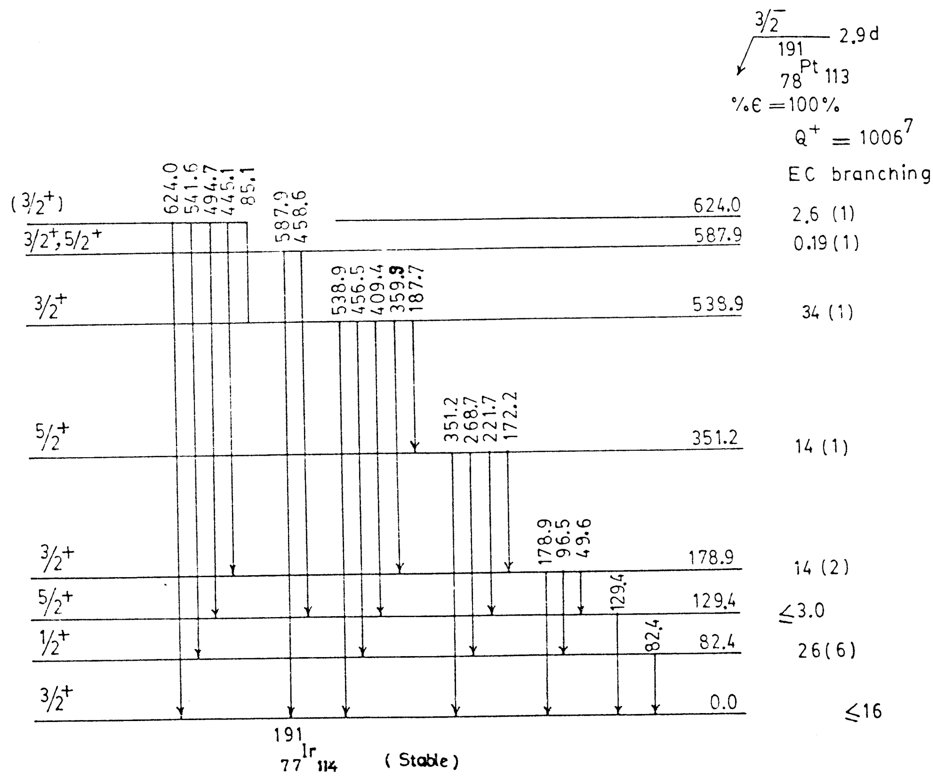

Fig. 2. Decay scheme of ^{191}Ir. Only the levels and transitions of interest are shown . All energies are in keV.

3. Relative K-Capture Probabilities

The ratio of K to total capture rate (P_K ratio) was determined using the sum coincidence method based on the summing of K X-rays and γ-rays in a single HPGe detector. When γ-rays and K X-rays in coincidence enter the sensitive volume of the detector within its resolving time, the photons from these two events are counted as a single event and a sum peak equal to the energy sum of the corresponding γ-ray and K X-ray is formed. From this sum peak the K-capture to the level, with which the respective K X-ray and γ-ray are in coincidence, can be estimated. For example, the relative K-capture probability to the 351 keV level is determined from the 351+K$_\alpha$ sum peak as follows. The K X-rays in cascade with the 351 keV γ-ray (see Fig. 2) which give rise to the 351+K$_\alpha$ sum peak arise due to:

(i) K-capture to the 351 keV level from EC decay;
(ii) K-conversion of the 187 keV γ-ray; and
(iii) K-capture to the 538 keV level connected to the 351 keV level through the 187 keV γ-ray.

Therefore the area under the 351+K$_\alpha$ sum peak can be written as

$$N^{\rm sum}_{351+{\rm K}_\alpha} = \omega_{\rm K} \frac{I_{{\rm K}_\alpha}}{I_{{\rm K}_\alpha}+I_{{\rm K}_\beta}} \epsilon_{{\rm K}_\alpha} \left\{ \left(1 - \frac{I_{187}}{T_{351}}\right) P_{\rm K}^{351} + \frac{I_{187}}{T_{351}} \left(\frac{\alpha_{\rm K}^{187}}{1+\alpha_{\rm T}^{187}} + P_{\rm K}^{538} \right) \right\} N_{351}, \quad (1)$$

Similarly the equations for the 178+K$_\alpha$ and 538+K$_\alpha$ sum peaks can be written as

$$N^{\rm sum}_{178+{\rm K}_\alpha} = \omega_{\rm K} \frac{I_{{\rm K}_\alpha}}{I_{{\rm K}_\alpha}+I_{{\rm K}_\beta}} \epsilon_{{\rm K}_\alpha} \left[\left(1 - \frac{I_{172}+I_{360}}{T_{178}}\right) P_{\rm K}^{178} + \frac{I_{172}}{T_{178}} \left\{ \left(\frac{\alpha_{\rm K}^{172}}{1+\alpha_{\rm T}^{172}} \right) \right.\right.$$

$$\left. + \left(1 - \frac{I_{187}}{T_{351}}\right) P_{\rm K}^{351} + \frac{I_{187}}{T_{351}} \left(\frac{\alpha_{\rm K}^{187}}{1+\alpha_{\rm T}^{187}} + P_{\rm K}^{538} \right) \right\}$$

$$\left. + \frac{I_{360}}{T_{178}} \left(\frac{\alpha_{\rm K}^{360}}{1+\alpha_{\rm T}^{360}} + P^{538} \right) \right] N_{178}, \quad (2)$$

$$N^{\rm sum}_{538+{\rm K}_\alpha} = \omega_{\rm K} \frac{I_{{\rm K}_\alpha}}{I_{{\rm K}_\alpha}+I_{{\rm K}_\beta}} \epsilon_{{\rm K}_\alpha} P_{\rm K}^{538} N_{538}, \quad (3)$$

where $I_{{\rm K}_\alpha}$ and $I_{{\rm K}_\beta}$ are the intensities of the K$_\alpha$ and K$_\beta$ X-rays of Ir, T_{351} and T_{178} are the sum of transition (γ+c.e.) intensities depopulating the 351 and 178 keV levels respectively, $\alpha_{\rm K}$ and $\alpha_{\rm T}$ are the K and total conversion coefficients of the respective γ-rays, $\omega_{\rm K}$ is the K-shell fluorescence yield for Ir, and $\epsilon_{{\rm K}_\alpha}$ and $\epsilon_{{\rm K}_\beta}$ are the absolute photopeak detection efficiences of the detector for K$_\alpha$ and K$_\beta$ X-rays of Ir.

Similar equations were written for the other sum peaks. The relative γ- and K X-ray intensities used were measured in the present work. The conversion coefficients $\alpha_{\rm K}$, $\alpha_{\rm T}$ and K-shell fluorescence yield $\omega_{\rm K}$ were taken from Lederer and Shirley (1978) and Browne (1989). The only sum peaks selected for analysis of $P_{\rm K}$ ratios were those which do not interfere with other peaks. The $P_{\rm K}$ ratios for three levels of ^{191}Ir, i.e. 178, 351 and 538 keV, are listed in Table 1.

Table 1. Relative K-capture probabilities to different levels of ^{191}Ir in the decay of ^{191}Pt

Level energy (keV)	Sum peaks analysed	P_K (exp)	P_K (theor) using Q_{EC} Exp.	P_K (theor) using Q_{EC} Present work
178	178+K$_\alpha$	0·824(34)	0·863	0·855
351	172+K$_\alpha$	0·820(44)		
	351+K$_\alpha$	0·825(45)		
		P_K (wt. av.) = 0·823(31)	0·855	0·849
538	360+K$_\alpha$	0·818(29)		
	360+K$_\beta$	0·816(35)		
	409+K$_\alpha$	0·817(33)		
	456+K$_\alpha$	0·814(37)		
	456+K$_\beta$	0·819(30)		
	538+K$_\alpha$	0·820(32)		
		P_K (wt. av.) = 0·817(13)	0·835	0·830

4. Absolute K X-ray Efficiencies

The absolute photopeak detection efficiencies for K$_\alpha$ and K$_\beta$ X-rays are usually determined from the analysis of γ–γ sum peaks. As there is no well-defined and clean γ–γ sum peak in ^{191}Pt decay, the β^- decay of ^{192}Ir to the levels of ^{192}Pt (Fig. 3) was therefore used for the determination of absolute K X-ray efficiencies in which K X-rays arise only due to K-conversion of γ-rays. The sum spectra for ^{192}Ir were taken using the same geometry and source-to-dectector distance as for ^{191}Pt. The 468 keV γ-ray is in cascade with the 136, 316, 416 and 593 keV γ-rays. The K X-rays from internal conversion of these γ-rays add with the 468 keV γ-ray giving rise to two sum peaks at 468+K$_\alpha$ and 468+K$_\beta$. The area under the 468+K$_\alpha$ sum peak can be written as

$$N^{\rm sum}_{468+{\rm K}_\alpha} = \omega_{\rm K}\frac{I_{{\rm K}_\alpha}}{I_{{\rm K}_\alpha}+I_{{\rm K}_\beta}}\epsilon'_{{\rm K}_\alpha}\left(\frac{I_{136}}{I_{468}}\frac{\alpha_{\rm K}^{136}}{1+\alpha_{\rm T}^{136}}+\frac{I_{416}}{I_{468}}\frac{\alpha_{\rm K}^{416}}{1+\alpha_{\rm T}^{416}}+\frac{I_{593}}{I_{468}}\frac{\alpha_{\rm K}^{593}}{1+\alpha_{\rm T}^{593}}\right.$$
$$\left.+\frac{I_{468}}{I_{316}}\frac{\alpha_{\rm K}^{316}}{1+\alpha_{\rm T}^{316}}\right)N_{468}\,. \qquad (4)$$

A similar equation can be written for the 468+K$_\beta$ sum peak. As already mentioned, $\alpha_{\rm K}$, $\alpha_{\rm T}$ and $\omega_{\rm K}$ were taken from the literature.

The values so obtained were for the K X-rays of Pt. The absolute efficiencies for the K X-rays of Ir were calculated from the relation

$$\epsilon'_{\rm abs}/\epsilon_{\rm abs} = \epsilon'_{\rm rel}/\epsilon_{\rm rel}\,, \qquad (5)$$

where $\epsilon'_{\rm abs}$, $\epsilon_{\rm abs}$, $\epsilon'_{\rm rel}$ and $\epsilon_{\rm rel}$ are absolute and relative efficiencies for the K X-rays of Pt and Ir respectively. The relative efficiencies of K$_\alpha$ and K$_\beta$ X-rays of Pt and Ir were obtained from the calibration curve for the 120 cm^3 HPGe detector (described in Section 2). The absolute photopeak efficiencies for the K$_\alpha$ and K$_\beta$ X-rays of Ir were found to be

$$\epsilon_{{\rm K}_\alpha} = 0\cdot0424(12), \qquad \epsilon_{{\rm K}_\beta} = 0\cdot0431(19).$$

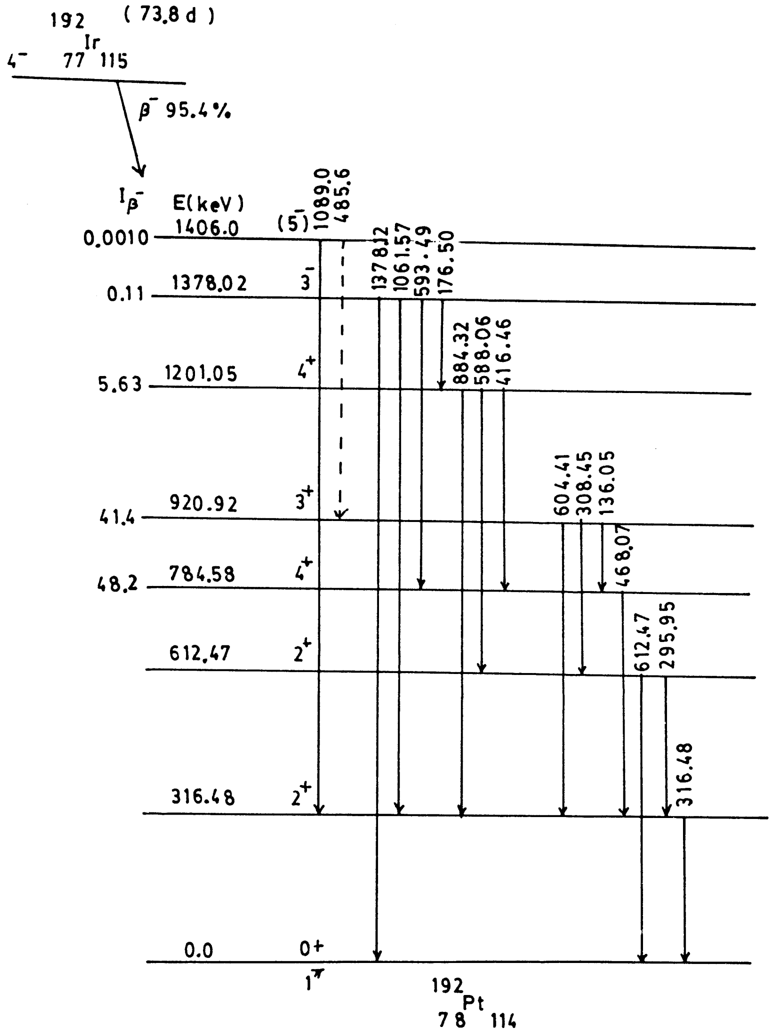

Fig. 3. Decay scheme of ^{192}Pt (used for the determination of absolute efficiencies of K_{α} and K_{β} X-rays of Ir).

5. Electron-capture Decay Energy and Theoretical P_K Ratios

The EC decay energies for ^{153}Gd and ^{175}Hf were calculated by von Dincklage (1985) using properties of their β decays. According to von Dincklage, the transition probabilities to two different members (at energies E_X and E'_X) of same rotational family can be expressed as

$$b(E'_X)/b(E_X) = \rho f(Q - E'_X)/f(Q - E_X), \quad (6)$$

where ρ is the ratio of reduced transition probabilities. The function f for EC of a nucleus ^{A}Z is related to the integrated Fermi function of continuous β decay through the equation

$$f(Q-E'_X, Z) = (1/m^2c^4)\sum_i \tfrac{1}{2}\pi g_i^2 (Q-E_X-W_i)^2 B_i\,, \quad (7)$$

where g_i are the amplitudes of the radial electron wavefunction, compiled by Bambynek *et al.* (1977). The electron exchange and overlap corrections B_i were also presented by Bambynek *et al.* The term $Q-E_X-W_i$ is the neutrino energy, where W_i is the binding energy. The binding energies are taken from Lederer and Shirley (1978). The calculated EC decay energy in the decay of ^{191}Pt, along with the two energy levels used for its determination, their spins and branchings, are listed in Table 2.

Table 2. Electron-capture decay energy in the decay of ^{191}Pt

Levels used to calculate Q_{EC}			Q_{EC}(calc.)^{A}	Q_{EC}(exp)
Energy (keV)	EC branching	Spin		
538·84	34(1)	$\frac{3}{2}^+$	975(12)	1006(7)
351·14	14(1)	$\frac{5}{2}^+$		

^{A} Calculated by the von Dincklage (1985) method.

The theoretical P_K ratios were calculated by using the Behrens and Janecke (1969) method. The expression for calculating these was given by Raeside *et al.* (1969):

$$\frac{P_{tot}}{P_K} \approx 1 + \left(\frac{Q-B_{L_I}}{Q-B_K}\right)^2 \left(\frac{\beta_{L_I}}{\beta_K}\right)^2 \left\{1+\left(\frac{\beta_{L_{II}}}{\beta_{L_I}}\right)^2\right\}\left\{1+\left(\frac{Q-B_{M_I}}{Q-B_{L_I}}\right)^2\left(\frac{\beta_{M_I}}{\beta_{L_I}}\right)^2\right\}, \quad (8)$$

where β_K, β_{L_I}, $\beta_{L_{II}}$ and β_{M_I} are the Coulomb amplitudes in Ir (in the present case) and listed by Bambynek *et al.* (1977), while B_K B_{L_I}, $B_{L_{II}}$ and B_{M_I} are the electron binding energies in Ir and are taken from Lederer and Shirley (1978). The energy Q is given by

$$Q = Q_{EC} - E(\text{level}). \quad (9)$$

Theoretical P_K ratios were calculated using Q_{EC} from the present work as well as the experimental value from Browne (1989). The theoretical P_K ratios along with the experimental values determined from the sum coincidence method are given in Table 1.

6. Conclusions

As evident from Table 1, the experimentally determined P_K ratios from the sum coincidence method agree with those calculated from the Behrens and Janecke (1969) theory. This is in line with the previous observations made in ^{75}Se, ^{153}Gd, ^{131}Ba and ^{169}Yb, where the sum coincidence method was successfully used to determine the relative K-capture probabilities. One more similarity between these nuclei was an increase in P_K ratios with an increase in energy available for decay. In other words, there is a decrease in P_K ratios with an increase in level energy. This is also observed in the present work.

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