Radiations of Osmium-193 and Osmium-191†

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The radiations of Os^{193} and Os^{191} have been examined in a thin-lens beta-ray spectrometer and in coincident scintillation spectrometers. Ten gamma rays and seven beta spectra have been detected in the decay of Os^{193}, revealing energy levels in Ir^{193} at 73, 138, 356, 388, 458, and 558 kev. In order of decreasing end-point energy, the relative intensities of the beta spectra of Os^{193} are estimated as 67, 6, 4, 2, 3, 13, and 5. The beta-ray spectrum of Os^{191} has been observed, and the K/L ratio of the 129-kev transition of Os^{191} has been measured as 2.4, corresponding to a mixture of 54% $E2$ in $M1$.

INTRODUCTION

RADIOACTIVE decay of Os^{193} and Os^{191} gives evidence of energy levels in Ir^{193} and Ir^{191}. Scintillation spectrometers and the higher resolution of a thin-lens spectrometer have been employed in examining the radiations emitted in the decay of these radioelements. Some of the energy levels observed are also accessible by Coulomb excitation. When possible, the level schemes determined by these two approaches have been compared.

The many radioactive sources employed were prepared for the most part by neutron irradiation of osmium in reactors at Brookhaven National Laboratory and Oak Ridge National Laboratory. On occasion, chemically processed samples were obtained from Oak Ridge, although most of the radioactive material was produced by neutron irradiation of metallic osmium supplied by the authors. In these latter instances, chemical separations were not necessary for assignment of the radiations, because half-life measurements provided sufficiently good identification. However, in performing coincidence studies, it was found necessary to remove traces of Ir^{192}. Because of the low abundance of Os^{184} and the comparatively long half-life of Os^{185}, only small amounts of this activity are present.

OSMIUM-193

Previous study[1–5] of the radiations of Os^{193} has resulted in the assignment to it of as many as five beta-ray spectra and nine gamma rays. In addition, a metastable level $T_{\frac{1}{2}}=(5.7\pm0.5)\times10^{-9}$ sec at 65 ± 5 kev above the ground state of the residual nucleus, Ir^{193}, has been reported by McGowan.[6] In the paragraphs following, measurements will be described, the results of which may be compared with the earlier data.

The sources for the measurement of the beta-ray continuum and internal conversion lines were mounted on thin backings of "Nu-Skin." An emulsion was made of the activated powdered osmium, and a drop was evaporated upon the Nu-Skin backing over an area about one-fourth inch in diameter. By means of a baffle adjustment, the resolution of the spectrometer was set at two percent. An anthracene crystal, 2 mm thick, was employed as the detecing device.

Fermi-Kurie plots of the beta-ray spectra of Os^{193} are shown in Fig. 1. Two components were resolved having end-point energies of 1105 ± 10 and 660 ± 20 kev. The harder spectrum had an abundance of about 77%. As will be shown later, these two beta-ray groups are themselves complex.

The internal conversion lines of the gamma rays of Os^{185}, Os^{191}, and Os^{193} are shown in Fig. 2. The energies of the electron lines and those of the corresponding gamma rays are given in Table I.

The spectrum of unconverted gamma rays was measured in a thin-lens spectrometer. Irradiated powdered osmium was placed within a brass capsule of sufficient thickness to absorb the hardest beta rays emitted, and over this source was slipped an aluminum

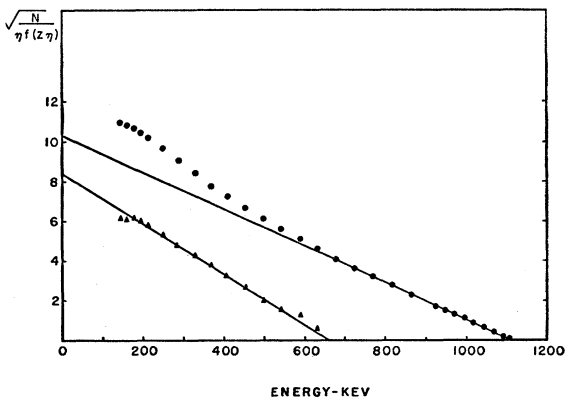

FIG. 1. Fermi plots of the beta spectra of Os^{193}.

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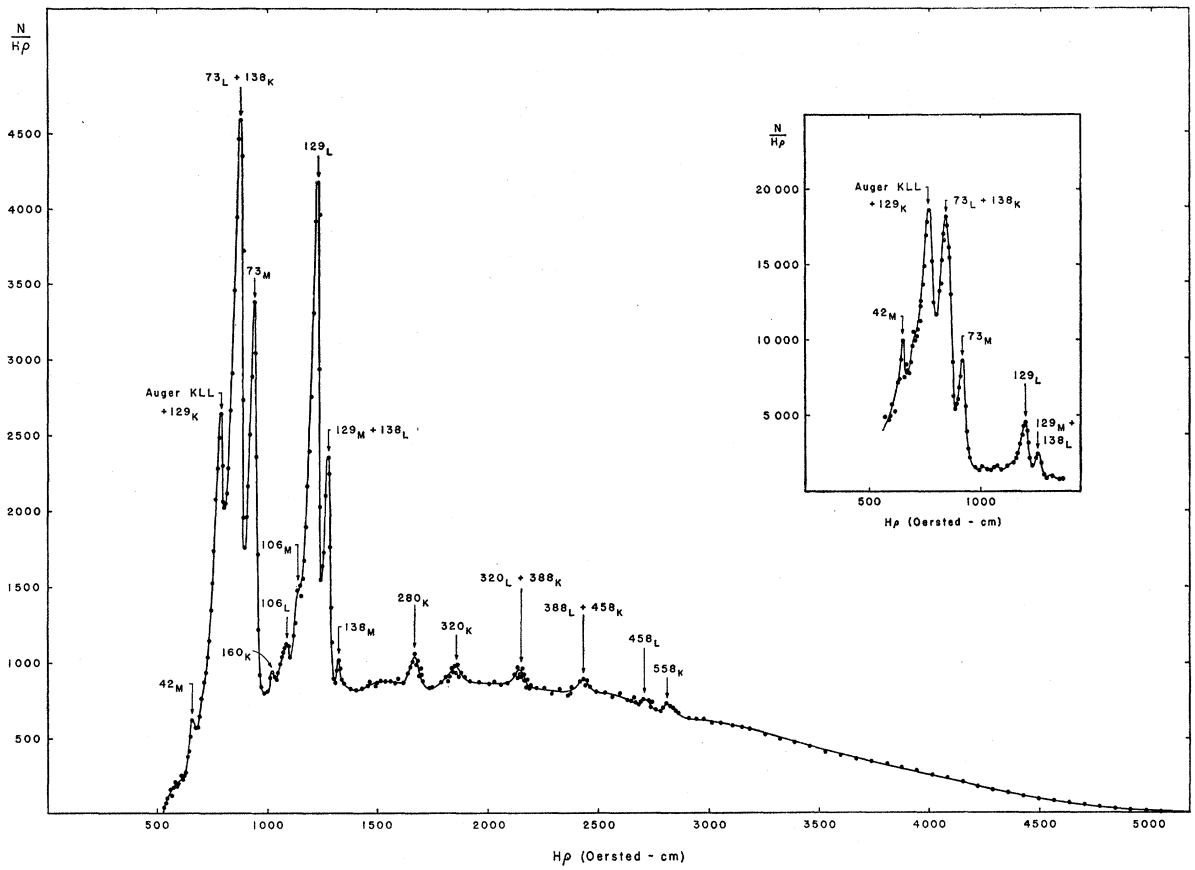

FIG. 2. Internal conversion lines of the gamma rays of Os^{193}, Os^{191}, and Os^{185}. (Energies are given in kev.) Insert at right shows the region of low energy corrected for variation with momentum of the detector efficiency.

cylinder that had a gold bottom 5 mg/cm² thick. Photoelectric secondaries were ejected from the gold for measurement in the lens. The spectrum of photoelectron lines is shown in Fig. 3 and the data obtained are summarized in Table II. The relative intensities of these unconverted quanta were estimated from the areas under the photoelectric peaks of the curve of Fig. 3.

TABLE I. Internal conversion lines of the gamma rays of Os^{185}, Os^{191}, and Os^{193}.

	Electron energy (kev)	Interpretation	
$H\rho$		Gamma-ray energy (kev)	Isotope
654	36	42 *M*	Os^{191}
776	51	129 *K*	Os^{191}
		Re *KLL* Auger	Os^{191}, Os^{193}
852	60±1	73 *L*	Os^{185}, Os^{191}, Os^{193}
		138 *K*	Os^{193}
921	70±1	73 *M*	Os^{185}, Os^{191}, Os^{193}
1020	85	160 *K*	Os^{185}
1080	94±1	106 *L*	Os^{193}
1138	103±1	106 *M*	Os^{193}
1208	115	129 *L*	Os^{191}
1265	125	129 *M*	Os^{191}
		138 *L*	Os^{193}
1318	135±1	138 *M*	Os^{193}
1665	203±2	280 *K*	Os^{193}
1850	243±2	320 *K*	Os^{193}
2150	311±3	388 *K*	Os^{193}
		320 *L*	Os^{193}
2435	380±4	458 *K*	Os^{193}
		388 *L*	Os^{193}
2710	449±4	458 *L*	Os^{193}
2820	477±5	558 *K*	Os^{193}

Beta-gamma coincidences in the decay of Os^{193} were measured with the use of two scintillation counters, one of anthracene for beta-ray detection, the other of NaI(Tl) for gamma-ray detection. The several beta-gamma coincidence curves so obtained are shown in Fig. 4. By employing the beta-gamma coincidence method, it was possible to resolve the two previously reported beta-ray groups into three components each; these measurements were obtained by confining the detection of gamma rays to a single gamma-ray energy in each instance. The quantum energies are indicated upon each portion of Fig. 4.

From the data of Figs. 4(A) and 4(B), beta-ray end-point energies were determined at 540±20 kev and 640±20 kev. From the magnitude of the beta-gamma coincidence rate of Fig. 4(C), and the conversion coefficient[7] of the 138-kev gamma ray, the intensity

[7] Alder, Bohr, Huus, Mottelson, and Winther, Revs. Modern Phys. **28**, 432 (1957).

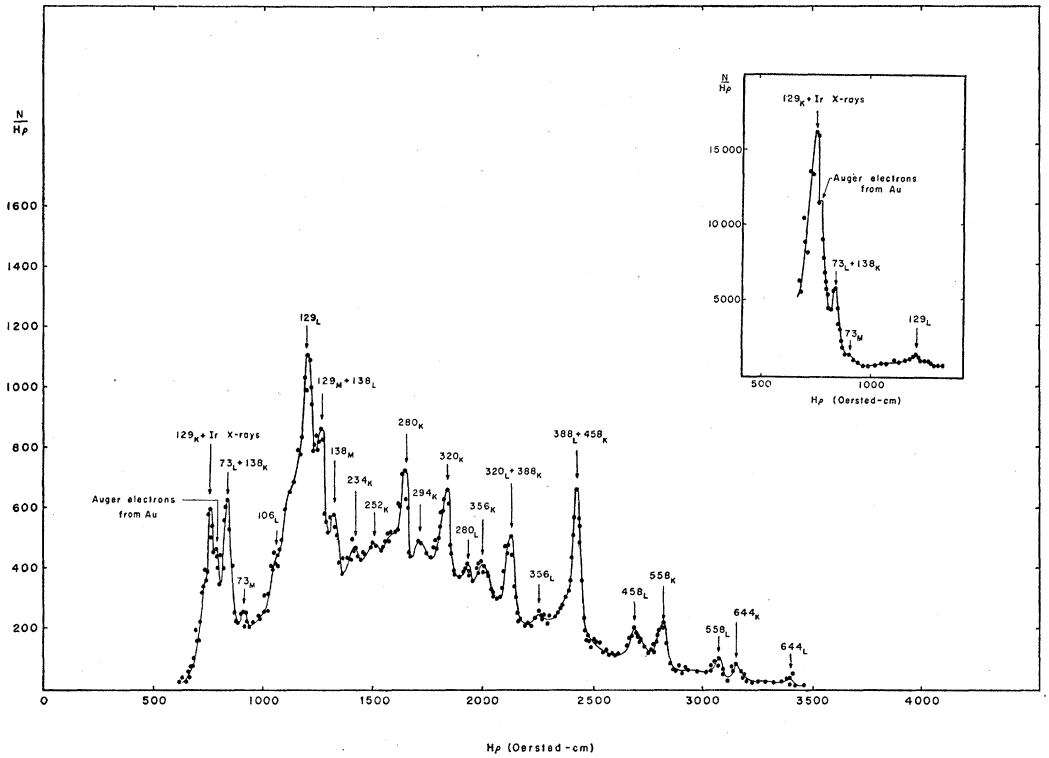

FIG. 3. Secondary electrons generated in a gold converter (5 mg/cm²) by the gamma rays of Os^{193}, Os^{191}, and Os^{185}. (Energies are given in kev.) Insert at right shows the region of low energy corrected for variation with momentum of the detector efficiency.

of the beta spectrum with an end-point energy of 960±25 kev was calculated to be 4%. A Fermi plot of the data of Fig. 4(D) yielded two beta-ray components having end-point energies of 1020±25 kev and 735±25 kev. The end-point energy of the softer component indicates a level of 356 kev and suggests a position in the decay scheme for the 280-kev gamma ray. The beta spectrum feeding the 73-kev level was calculated to have an intensity of about 6%. This percentage was obtained by considering the beta-gamma coincidences of Fig. 4(D) lying beyond a beta-ray energy of 735 kev, and assuming a conversion coefficient of 3 for the $M1+E2$ transition of 73-kev energy.

TABLE II. Photoelectron lines of the gamma rays of Os^{185}, Os^{191}, and Os^{193}.

		Interpretation		
$H\rho$	Electron energy (kev)	Gamma-ray energy (kev)	Isotope	Relative intensity of the unconverted quantum
764	50	129 K 63 L (Ir x-ray)	Os^{191} Os^{191}, Os^{193}	
790	53	KLL Auger electrons from Au	Os^{185}, Os^{191}, Os^{193}	
845	59±1	73 L 138 K	Os^{185}, Os^{191}, Os^{193} Os^{193}	
915	69±1	73 M	Os^{185}, Os^{191}, Os^{193}	
1052	90±2	106 L	Os^{193}	
1205	115	129 L	Os^{191}	
1270	126	129 M 138 L	Os^{191} Os^{193}	
1320	135±1	138 M	Os^{193}	
1415	153±1	234 K	Os^{193}	
1507	171±2	252 K	Os^{193}	1
1650	200±2	280 K	Os^{193}	15
1712	213±2	294 K	Ir^{192}	
1838	240±2	320 K	Os^{193}	21
1950	265±2	280 L	Os^{193}	
1995	276±3	356 K	Os^{193}	6
2130	307±3	320 L 388 K	Os^{193} Os^{193}	32
2275	341±3	356 L	Os^{193}	
2425	378±4	388 L 458 K	Os^{193} Os^{193}	100
2690	444±4	458 L	Os^{193}	
2820	477±5	558 K	Os^{193}	45
3070	542±5	558 L	Os^{193}	
3155	563±6	644 K	Os^{185}	
3400	629±6	644 L	Os^{185}	

Using a slow-fast coincidence circuit and a 20-channel pulse-height analyzer, gamma-gamma coincidences were measured by placing the channel of a single-channel analyzer at each photopeak of the gamma-ray spectrum. Coincidences were observed between gamma rays of 73 and 280 kev, 138 and 252 kev, and 138 and 320 kev. No coincidences were observed between the 558-, 458-, and 388-kev gamma rays and any other gamma rays of the spectrum. The foregoing beta-gamma and gamma-gamma coincidence experiments have led to the establishment of a level structure for the residual nucleus, Ir^{193}. They also indicate the presence of seven beta spectra. The intensities of the unconverted quantum radiations (Table II) coupled with certain assumptions concerning some of the conversion coefficients can lead to calculations of the relative intensities of the beta-ray spectra

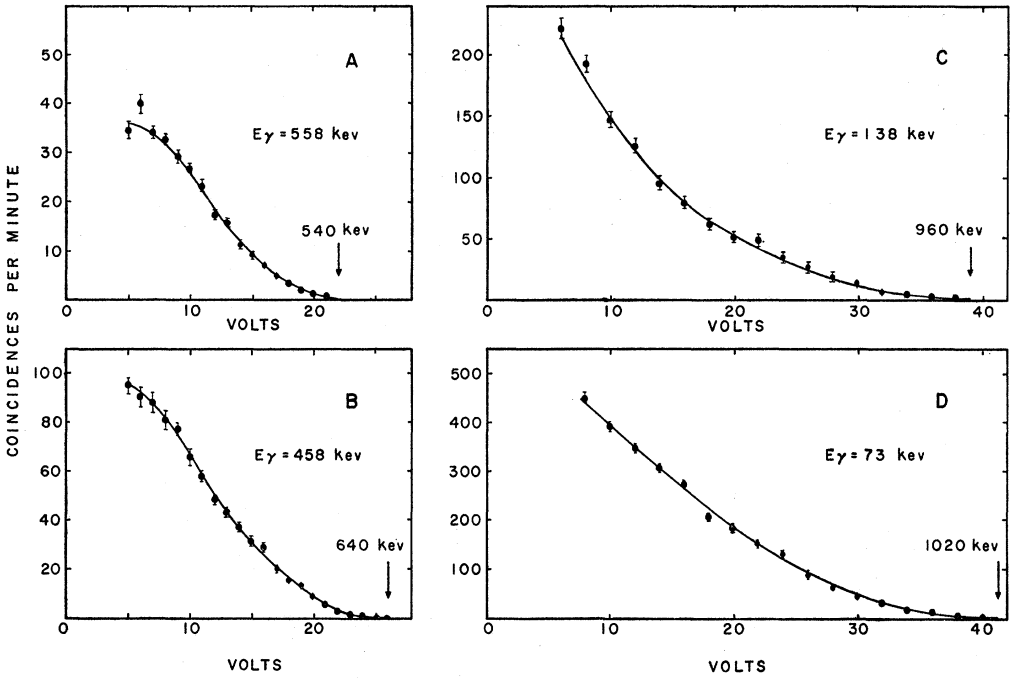

FIG. 4. Beta-gamma coincidence curves obtained in the decay of Os^{193}.

and finally to calculations of values of logft. Data obtained for Os^{193} are given in Table III.

The results of the previously described measurements and calculations are summarized in the disintegration scheme of Os^{193} shown in Fig. 5. The spin of the ground state of Ir^{193} has been measured[8] as $\frac{3}{2}$. According to the shell model, the orbital for this level should be $d_{\frac{3}{2}}$. From the systematics of the odd-A nuclei of this region and from a further consideration of the shell-model theory, the orbital of the first excited state at 73 kev can be taken as $s_{\frac{1}{2}}$. From Coulomb excitation experiments[9] the spin and parity of the second excited state of Ir^{193}, lying at 138 kev, have been determined as $\frac{5}{2}+$. The position of this level corresponds properly to the calculated position of the first excited rotational level of the ground-state band ($K=\frac{3}{2}$). The level excited at 356 kev is apparently not the same as the 368-kev level observed in Coulomb excitation experiments,[9] since the 280-kev gamma ray was found to be in prompt coincidence with the 73-kev gamma ray. Little can be said about the orbitals of the remaining more highly excited states of Ir^{193} because all of the beta spectra of Os^{193} are first forbidden in character and the spin of the ground state of Os^{193} is not precisely known. Following the results of the shell model, the ground-state spin of Os^{193} with 117 neutrons could be either $p_{\frac{3}{2}}$ or $p_{\frac{1}{2}}$. The

TABLE III. Beta spectra of Os^{193}.

$E_{\beta max}$ (kev)	Relative intensities (percent)	Logft
1105	67	6.3
1032	6	8.3
967	4	8.4
749	2	8.4
717	3	8.2
647	13	7.2
547	5	7.5

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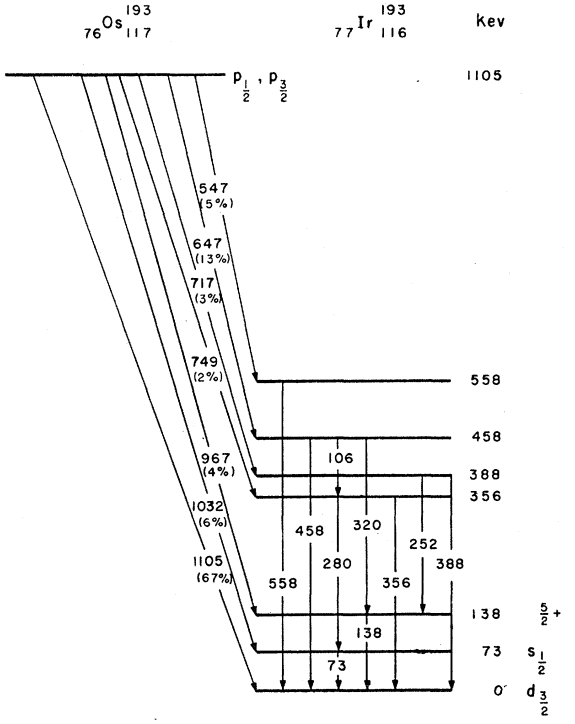

FIG. 5. Disintegration scheme of Os^{193}.

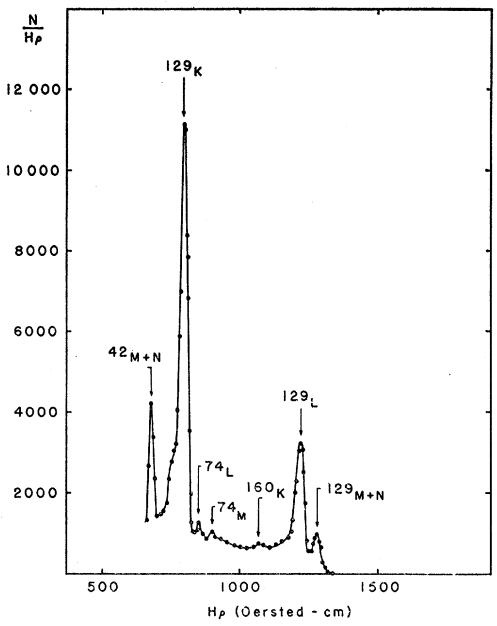

FIG. 6. Beta-ray spectrum and internal conversion lines of Os^{191}. (Energies are given in kev.)

measured spin values[10] of the ground states of nuclei containing 117 neutrons (Pt^{195} and Hg^{197}) are in each case $\frac{1}{2}$. Since the second excited rotational level of the ground-state band ($K=\frac{3}{2}$) of Ir^{193} is not excited by the beta-decay process, the ground-state spin of Os^{193} may possibly be assigned as $\frac{1}{2}$. Ir^{193} has been formed[11] in a metastable state of spin 11/2 by two successive neutron captures in Ir^{191}. Owing to the operation of selection rules, this level is not excited in the beta decay of Os^{193}.

OSMIUM-191

Os^{191} (15 days) has been shown[12] to decay with the emission of beta rays of a maximum energy of 142 kev followed by two gamma rays in cascade with energies of 42 and 129 kev. The beta-ray spectrum and conversion lines of Os^{191} are shown in Fig. 6. To obtain these data, the baffle system of the spectrometer was adjusted to give a resolution of 1.5%. Superposed upon the beta spectrum of Os^{191} are also faint conversion lines showing evidence of the presence of the 74-, 120-, and 160-kev gamma rays of Os^{185}.

The K-shell internal conversion coefficient (α_K) of the 129-kev gamma ray was measured by a comparison method wherein the known value[13] of α_K for the 279-kev line of Hg^{203} was utilized. The areas of the internal conversion electron lines of these two gamma rays were measured in the thin-lens spectrometer under identical conditions. Subsequently these same sources were employed to measure their respective unconverted gamma-ray spectra with a scintillation spectrometer including a 5-inch thick NaI(Tl) crystal. In these later observations a collimator was employed so that a pencil of gamma rays fell at the center of the crystal. The required conversion coefficient is given by $\alpha_K(129)=\alpha_K(279)(\epsilon_2/\epsilon_1)(a_1/a_2)(A_2/A_1)$, where the subscript "1" refers to the gamma ray of 279 kev and the subscript "2" to one of 129 kev. The quantity ϵ is the intrinsic detection efficiency of the 5-inch crystal; a is the area under the pulse-height distribution of unconverted quantum radiation; A is the area under the conversion line. This experimentally determined value of $\alpha_K(129)$ is 2.1 ± 0.2.

The Auger electrons released by the 62-kev x-rays of iridium could not be resolved from the K-shell conversion line of the 129-kev gamma ray. It was therefore necessary to correct A_2 for their presence. This correction was obtained from the equation

$$\frac{1-f}{f}=\alpha_K(279)\frac{\epsilon_3}{\epsilon_1}\frac{a_1}{a_3}\frac{A_3}{A_1}$$

by solving for A_3, the area under the conversion line peak contributed by the Auger electrons. The quantity f is the fluorescence yield of the x-rays of iridium.

From the data of Fig. 6 it was also possible to determine the K/L and $L/(M+N)$ ratios of the 129-kev gamma ray of Os^{191}, and they were found to be, respectively, 2.4 and 3.6. From the observed K/L ratio and the conversion coefficients of Rose,[14] the 129-kev transition was calculated to be a mixture of 54% $E2$ and 46% $M1$. According to theoretically computed conversion coefficients for the K shell, this mixture would yield conversion coefficients of 1.5 [14] and 1.4,[15] values lower than the observed value of 2.1 ± 0.2. Previously reported values of this conversion coefficient are 0.5,[16] 1.36,[17] 2.0,[18] 2.07,[19] 3.2.[20]

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