Studies of Decay Schemes in the Osmium-Iridium Region. I. Isomers Os^{190m}(10 min) and Os^{189m}(5.7 hr)*

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While the decay-scheme of the even-even isomer Os^{190m}(10 min) has some similarity with that of the "rotational" isomer Hf^{180m}, it differs from the latter in that Os^{190} lies in the transition region between the nuclei with rotational and those with near-harmonic level schemes. It was previously believed that the lifetime determining transition in Os^{190m} was a 620-kev transition followed by three lower energy gamma rays. We find, however, that the isomeric transition is a previously overlooked 38.4-kev $M2$ transition with an $|M|^2=2.6\times10^{-9}$ ("K forbidden"). It is followed by four successive γ rays. Internal conversion electron studies by means of an intermediate image spectrometer yielded γ-ray energies of 187±1 kev, 359±2 kev, 500±3 kev, and 614±3 kev. All four transitions are of electric quadrupole character, suggesting that the levels populated are 8+, 6+, 4+, 2+, 0+ (ground state). Delayed coincidence measurements by A. W. Sunyar show that the two lowest energy transitions of 359 and 187 kev take place between the levels 4+→2+ and 2+→0+ respectively and it may be expected that also the two higher energy γ rays follow each other in the order of decreasing energy. However, in contrast to the level spacings in true rotational nuclei, the level energies are far from being proportional to $I(I+1)$, and cannot even be represented with the help of a correction term $\sim I^2(I+1)^2$.

The six-hour osmium isomer, which was discovered by T. C. Chu and assigned by him to Os^{190m}, was identified instead as Os^{189m}. The half-life was found to be 5.7±0.1 hour. The isomer decays by a 30.0-kev $M3$ transition to the ground state with $|M|^2=2.2\times10^{-5}$.

INTRODUCTION

THE disintegration scheme of Os^{190m} [1] was studied in the course of an investigation of the K-capturing iridium isotopes with even mass number, which was undertaken for the following reasons:

Previously it had been shown that groups of "near-harmonic" even-even nuclei exist between the nuclei with filled neutron and/or proton shells—nuclei which have been more or less successfully treated by shell model analysis—and the strongly deformed nuclei in the rare earths and heavy element regions, whose properties were so successfully interpreted by Bohr and Mottelson.[2] The level energies of the near-harmonic nuclei, as well as the probabilities for transitions between their levels, have been interpreted by using the Bohr-Mottelson Hamiltonian for the weak coupling case.[3] This interpretation is in agreement with important new evidence recently obtained by various authors.[4] The transitions from the near-harmonic pattern of level schemes to the rotational pattern characterizing the strong-coupling regions take place more or less abruptly at $88<N<90$ ($A\sim150$)[3] and at $86<Z<88$ ($A\sim220$).[5] According to Mottelson and Nilsson[6] the "breaking up of the $h_{11/2}$ shell" is responsible for the dramatic change as a function of neutron number. It seems plausible that the reason for the change of nuclear shape with increasing proton number is essentially the same.

As it seemed of great interest to investigate whether there exist nuclear level schemes intermediate between the two extremes of near-harmonic and rotational, it was decided to study the third existing transition region consisting of the even-even osmium ($Z=76$) nuclei, which are flanked on one side by the rotational hafnium ($Z=72$) and wolfram ($Z=74$) isotopes and on the other by the near-harmonic platinum ($Z=78$) isotopes. A glance at a graph (Fig. 1) presenting the energies of the first excited (2+) states (E_1) of even-even nuclei for $60\leqslant Z\leqslant78$ shows that such a study would be indeed

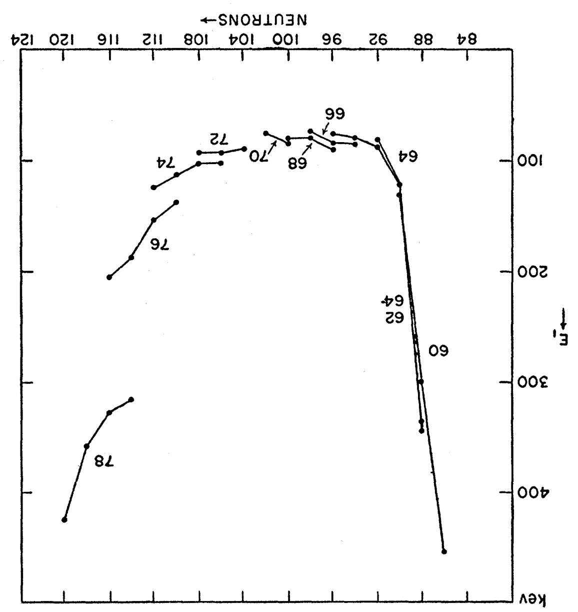

FIG. 1. Energies of first excited states of even-even nuclei for $60\leqslant Z\leqslant78$ as function of neutron number.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Scharff-Goldhaber, Alburger, Harbottle, and McKeown, Bull. Am. Phys. Soc. Ser. II, **2**, 25 (1957).
[2] A. Bohr and B. R. Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **27**, No. 16 (1953).
[3] Gertrude Scharff-Goldhaber and J. Weneser, Phys. Rev. **98**, 212 (1955).
[4] See Gertrude Scharff-Goldhaber, Proceedings of the University of Pittsburgh Conference, June 6–8, 1957 (unpublished).
[5] G. Scharff-Goldhaber, Phys. Rev. **103**, 837 (1956).
[6] B. R. Mottelson and S. G. Nilsson, Phys. Rev. **99**, 1615 (1955); S. G. Nilsson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **29**, No. 16 (1955).

promising, since the values E_1 for the osmium nuclei bridge the large energy gap occurring between $88<N<90$. The nuclei Os^{186} and Os^{188} had so far been mainly studied as decay products of the radioactive isotopes Re^{186} and Re^{188},[7] but as both of these have ground states with $I=1$, no osmium levels with $I>2$ are populated in their decay. However, since the rotational band belonging to the ground state of an even-even nucleus has a spin sequence 0, 2, 4, 6, 8, $\cdots$, the higher spin levels are of particular interest in this context. As it was known that at least some of the radioactive even-A Ir nuclei have higher spins, we decided to study systematically their decay by K capture and/or positron emission. The work was complicated by two difficulties: (1) Since osmium is a toxic element, it has so far not been possible to product enriched osmium isotopes, which would have served as prolific sources of specific radioactive iridium isotopes via the (d,p) process. (2) Two pairs of Ir isotopes have similar half-lives: one pair consists of Ir^{190} and Ir^{189} ($\sim$12 days), the other pair consists of Ir^{187} (10.4 hr) and Ir^{186} (16.6 hr)[8]; the second pair was identified during the course of these studies. However, these difficulties were finally overcome by using enriched Re isotopes and employing the $Re^{185,187}(\alpha,xn)_{x=1,2,3}$ process with suitable alpha-particle energies, which enabled us to study each Ir Isotope separately. Our results showed that the level schemes of the nuclei Os^{186}, Os^{188}, Os^{190}, and Os^{192} represent indeed a gradual transition from the rotational to the near-harmonic pattern.[4]

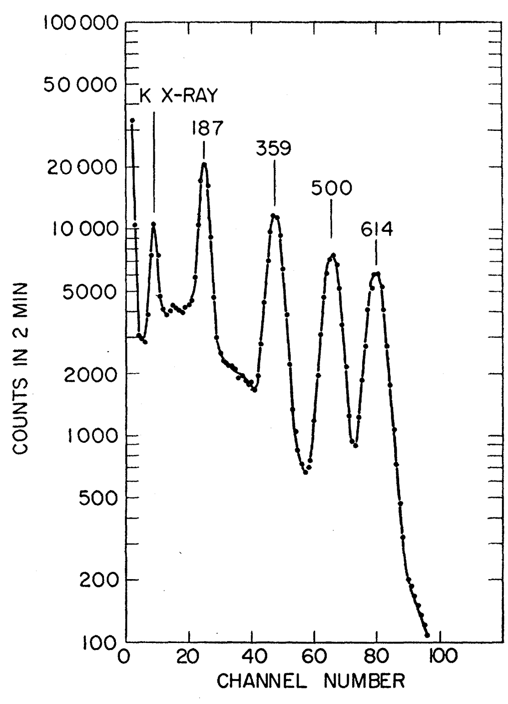

FIG. 2. Scintillation spectrum of Os^{190m} (10 min) taken with a 3-in. NaI(Tl) crystal. Gamma-ray energies are given in kev.

In this paper the evidence for the levels of Os^{190} populated in the decay of the isomer Os^{190m} will be presented. The disintegration scheme of the isomer Os^{189m} was a by-product of this work.

A. DECAY OF Os^{190m}(10 min)

The 10-min Os activity was discovered in 1950 by Chu,[9] who was also able to assign its correct mass number. It was observed to grow from a 3-hr Ir activity, which was produced in two different ways, by deuteron bombardment of Os and by α-particle bombardment of Re^{187}.

A study of the radiations from the 10-min activity by Aten, Feyfer, Sterk, and Wapstra[10] led to very interesting results: they found that it emitted four γ rays in cascade, with energies of 186, 360, 510, and 620 kev. The lowest energy γ ray fitted in well with the known regularities of first excited states of even-even nuclei and was therefore assumed to be an electric quadrupole transition leading to the ground state. The intensity of the 620-kev γ rays seemed slightly lower than that of the other three γ rays and was therefore thought to be the isomeric transition. Lifetime considerations led to the multipole assignment $M4$. The 510- and 360-kev γ rays were assumed to follow each other in the order of decreasing energy and were believed to be $E2$ in accordance with the Bohr-Mottelson rotational pattern. The authors further reported that the 10-min Os^{190m} is not produced by K capture of the ground state of Ir^{190} (12 day) nor by the decay of Re^{190} (2.8 min). They also reported a third method of producing Ir^{190m} (3 hr), namely by fast neutron bombardment of iridium.

The decay scheme of Os^{190m} suggested by Aten *et al.* bears some resemblance to that of Hf^{180m} [11,12] in that it also shows a fourfold cascade, but it differs from it in four important aspects:

(1) The energy of the first excited state of Os^{190} is much higher than that of Hf^{180}.

(2) The ratios of the energies of the second and third excited states are not proportional to $I(I+1)$.

(3) It does not include an 8+ state (fourth excited state of Hf^{180}).

(4) The isomeric transition is in no way analogous to that in Hf^{180m} which is a low-energy (57 kev) $E1$ transition slowed down by an enormous factor ($\sim10^{16}$) compared to a single proton transition[12]; this large

[7] Most recently by K. O. Nielsen and O. B. Nielsen, Nuclear Phys. **5**, 319 (1958).
[8] Scharff-Goldhaber, McKeown, Alburger, and Hudis (to be published).
[9] F. C. Chu, Phys. Rev. **79**, 582 (1950).
[10] Aten, Feyfer, Sterk, and Wapstra, Physica **21**, 740 (1955).
[11] Mihelich, Scharff-Goldhaber, and McKeown, Phys. Rev. **94**, 794(A) (1954). Hf^{180m} was first recognized to be the prototype of a rotational nucleus by A. Bohr and B. R. Mottelson, Phys. Rev. **90**, 717 (1953).
[12] Scharff-Goldhaber, McKeown, and Mihelich, Bull. Am. Phys. Soc. Ser. II, **1**, 206 (1956); and to be published.

hindrance factor has been interpreted as a consequence of the operation of the K selection rule.[13]

Since, as was pointed out before, Os^{190} lies in the poorly known transition region between the nuclei with pure rotational pattern and those with a near-harmonic pattern, it seemed important to establish the multipole order, and, if possible, the sequence of the four transitions. We further planned to gain more information on the nature of the isomeric transition.

Experimental Procedure and Results

The Os^{190m} sources were produced by bombarding ~150-mg Os metal powder with 20-Mev deuterons, separating the Ir from the target and then successively "milking" 10-min Os daughters which had grown from the 3-hr Ir parent. The decay was followed over six half-lives by means of a scintillation counter and $T_{\frac{1}{2}}$ was found to be 9.9±0.1 min. Figure 2 shows the scintillation spectrum obtained with a 3-in. NaI(Tl) crystal. The energies and also the intensities agreed fairly well with those found by Aten *et al.*, but the intensity of the highest energy γ-ray was incompatible with an $M4$ assignment. If one makes the plausible assumption that the lowest energy γ-ray is $E2$, which also agrees with the Coulomb excitation data,[14–16] the intensities of the three other γ-rays are compatible with electric quadrupole assignments. This leaves the isomeric lifetime unexplained.

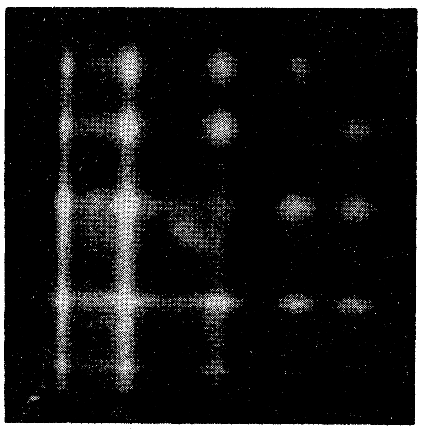

FIG. 3. Coincidence picture obtained from Ir^{190m} (3 hr), containing Os^{190m} (10 min) in equilibrium. The picture confirms the result of Aten *et al.*[10] that the four γ rays whose energies are given in Fig. 2 are in cascade. [The diagonal spot is due to the coincidence of two γ rays of 317 and 297 kev following the beta-decay of Ir^{192} (75 day), a small amount of which was present in the source.]

Figure 3 gives a graphic confirmation of the finding[10] that the four gamma rays are in cascade. It was obtained by means of the coincidence sorter technique developed by Grodzins.[17] A 3-hr Ir^{190m} source is placed between two scintillation spectrometers forming part of a coincidence circuit. Whenever a coincidence occurs, the pulses from the two crystals are stretched at their maxima and applied to the X and Y axes, respectively, of an oscilloscope. Thus a spot appears on the oscilloscope face at the $X-Y$ position corresponding to the energies of two coinciding γ rays. The coincidence spots are of course reflected on the 45° line. No lower energy γ ray coinciding with the 4 others was found.

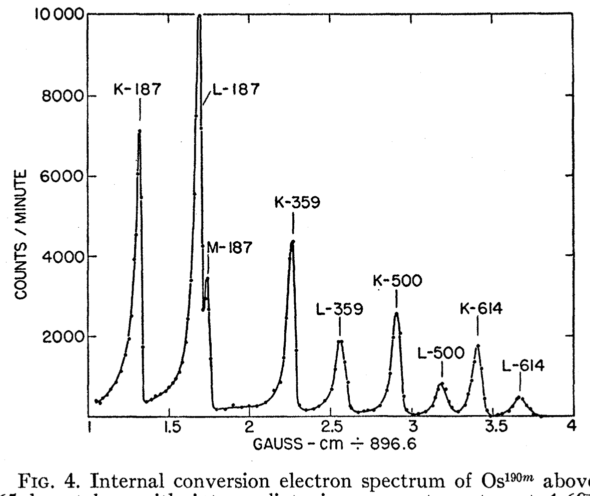

FIG. 4. Internal conversion electron spectrum of Os^{190m} above 65 kev taken with intermediate image spectrometer at 1.6% resolution. The source thickness was 0.7 mg/cm². The data have been corrected for the decay of the 10-min activity and for counter background.

We then studied the internal conversion electrons of the 10-min activity with an intermediate image spectrometer built by one of us (D. E. A.).[18] The instrument is equipped with a Geiger counter with a 3.5-mg/cm² mica window. Figure 4 shows the conversion electron spectrum with the well-separated K and L lines of the four transitions. The energies obtained are given in the figure: the energies of the two higher energy γ-rays are slightly lower than those given by Aten *et al.*, and are in good agreement with our scintillation spectrum. From the areas of the lines shown in Fig. 4 we obtained the conversion coefficients for the K and L shells of the three higher energy transitions by using for normalization the L conversion line of the 187-kev transition which is known to be $E2$. The theoretical conversion coefficient for this line was obtained by interpolating the values given by Rose, Goertzel, and Swift.[19] The L-conversion line was preferred for this purpose, as the correction for window absorption and source thickness was not negligible for the 187-kev K conversion line; especially the source thickness correction would

[13] Alaga, Alder, Bohr, and Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **29**, No. 9 (1955), p. 9.

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

[15] P. Stelson and F. McGowan (private communication).

[16] Barloutaud, Lévêque, Lehmann, and Quidort, J. phys. radium **19**, 60 (1958).

[17] L. Grodzins, Rev. Sci. Instr. **26**, 1208 (1955).

[18] D. E. Alburger, Rev. Sci. Instr. **27**, 991 (1956).

[19] Rose, Goertzel, and Swift, privately circulated tables on K and L conversion coefficients.

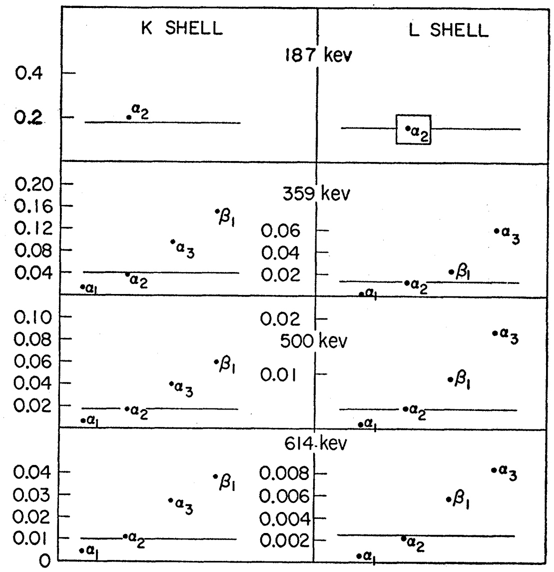

FIG. 5. Comparison of theoretical (•) and measured (—) conversion coefficients for the γ rays from Os^{190m} (10 min). The measured conversion coefficients differ by less than 10% from the theoretical ones for $E2$ transitions (α_2). The 187-kev L-conversion line has been used for normalization.

have been difficult to estimate. In Fig. 5 the measured conversion coefficients are compared with the theoretical ones[19] for $E1$, $E2$, $E3$, and $M1$ transitions. Higher electric or magnetic multipoles would yield still higher conversion coefficients. From this analysis it follows that all four transitions are electric quadrupole. No crossover transitions were observed. A spin sequence 0, 2, 4, 6, 8 (even parity) may thus be assumed, just as in the case of Hf^{180m}.

We then searched for a lower energy electron line representing the isomeric transition, but down to the cutoff energy for conversion electrons of ~65 kev none was found.

To be able to extend the range of the instrument to lower electron energies, we constructed a Geiger counter with a VYNS[20] window 150 μg/cm^2 thick, which was supported by a thin metal grid. The cutoff of this counter was at ~8-kev electron energy. In order to improve the resolution, the 10-min Os^{190m} sources were electroplated on platinum foil from a carrier-free solution. Figure 6 shows the spectrum obtained in this manner, which consisted of the L, M, and N lines of a 38.4-kev transition. From this graph one obtains the following conversion coefficient ratios: $(L_I+L_{II})/L_{III}=1.9\pm0.4$; $M_{tot}/L_{tot}=0.36\pm0.04$; $N_{tot}/L_{tot}=0.11\pm0.03$.

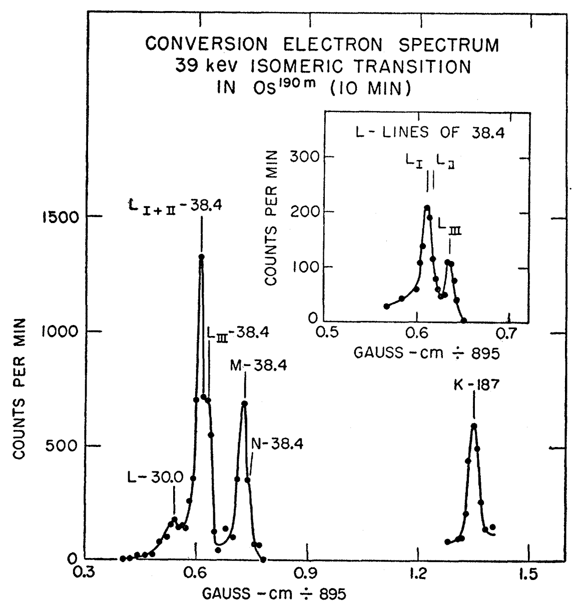

FIG. 6. Low-energy region of the internal conversion electron spectrum of Os^{190m} taken with intermediate image spectrometer at 1.6% resolution. The L-30.0 kev line is caused by the presence of a small admixture of Os^{189m} (5.7 hr). The curve shown in the inset was taken at 1% resolution. The sources used were electroplated on platinum foil from a carrier-free solution. The data were corrected for decay of the 10-min activity and for counter background.

Discussion

Table I lists the theoretical conversion coefficient for the 38.4-kev transition. In the fourth and fifth lines the $(L_I+L_{II})/L_{III}$ and M_{tot}/L_{tot} ratios are compared with the measured ones. In the seventh line the measured upper limit for the unconverted γ rays of 0.5% per transition is compared with the various theoretical values, which allows us to exclude both magnetic and electric dipole transitions. The relative positions of the L_I+L_{II} and L_{III} lines indicate that the L_I conversion line is more intense than L_{II}. This information, together with the measured $(L_I+L_{II})/L_{III}$ and M_{tot}/L_{tot} ratios, leads to the conclusion that the transition is $M2$. It is very highly forbidden, by a factor[21] 4×10^{-9}.

Assuming that the 614-kev γ ray follows the isomeric transition, we searched for an L-conversion electron line corresponding to a crossover $M4$ transition of 652 kev. The L line was chosen because the K-conversion line of this transition would overlap the 614-kev L-conversion line. No such line was found; taking into account the background it was estimated[21] that $(|M|^2)_{652\ \mathrm{kev}}<10^{-5}$.

Figure 7 summarizes our results in the form of a proposed disintegration scheme of Os^{190m} shown in juxtaposition with the decay scheme of Hf^{180m}. The place given to the 359-kev transition in the Os^{190} level scheme is based on a delayed coincidence experiment by Sunyar which showed that the 359-kev γ ray is located above the 187-kev line, and follows the two higher energy γ rays.[22] The experimental determination

[20] B. D. Pate and L. Yaffe, Can. J. Chem. **33**, 15 (1955).
[21] The formulas for single-particle lifetimes used were those given by S. A. Moszkowski, in *Beta- and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (Interscience Publishers, Inc., New York, 1955), p. 391.
[22] A. W. Sunyar (to be published).

TABLE I. Comparison of the measured $(L_{\rm I}+L_{\rm II})/L_{\rm III}$ ratio (see Fig. 6) with the theoretical values[19] for the 38.4-kev isomeric transition in Os^{190m}(10 min). Each number in parentheses indicates the power of ten by which the preceding entry should be multiplied. Together with the upper limit on unconverted γ-rays this information indicates that the transition is $E2$, $E3$, or $M2$, although the measured value differs somewhat from any of the three theoretical values. The measured value for $M_{\rm tot}/L_{\rm tot}$ agrees best with the theoretical one for $M2$. Moreover, the position of the peak of the $L_{\rm I}+L_{\rm II}$ lines (Fig. 6) indicates that $L_{\rm I}$ is much stronger than $L_{\rm II}$, which is only compatible with an $M2$ transition. This choice is also supported by the level sequence expected for deformed nuclei as given by Nilsson.

		Theoretical						
	Experimental	α_1	α_2	α_3	α_4	β_1	β_2	β_3
$L_{\rm I}$		3.00(−1)	3.00(0)	1.7(+2)	5.8(3)	1.25(+1)	5.4(+2)	1.10(+4)
$L_{\rm II}$		2.00(−1)	1.25(+2)	9.0(+3)	2.7(5)	1.05(0)	3.9(+1)	8.00(+2)
$L_{\rm III}$		2.70(−1)	1.10(+2)	9.0(+3)	3.3(5)	1.15(−1)	2.2(+2)	4.30(+4)
$M_{\rm tot}$		2.9(−1)	1.17(+2)	9.92(+3)			3.32(+2)	
$(L_{\rm I}+L_{\rm II})/L_{\rm III}$	1.9 ±0.4	1.85	1.16	1.02	0.84	118	2.6	0.274
$M_{\rm tot}/L_{\rm tot}$	0.36±0.04	0.038	0.49	0.55			0.42	
$N_{\rm tot}/L_{\rm tot}$	0.11±0.03							
Unconverted γ rays per transition	$<5\times10^{-3}$	5×10^{-1}	2×10^{-3}	3.5×10^{-5}	1×10^{-6}	7×10^{-2}	9×10^{-4}	1.4×10^{-5}
$\tau_{\frac{1}{2}}$(sec)	594						1.57×10^{-6}	
$\lvert M\rvert^2$							2.6×10^{-9}	

of the sequence of the 614- and 500-kev γ rays has so far not been possible, but it is reasonable to assume that the given order is correct. The character of the isomeric state as deduced from the conversion coefficients is 10−. This assignment is compatible with Nilsson's[6] sequence of orbits: Namely, a pair of 9/2− neutrons is split and one neutron moved into an adjacent 11/2+ orbit.

We have noted before that Aten *et al.*'s[10] work shows for the 4+ and 6+ levels an appreciable deviation from proportionality with $I(I+1)$. We see now that this deviation is even more pronounced for the 8+ level. The level energies cannot even be interpreted by adding a term $\sim I^2(I+1)^2$ as suggested by Bohr and Mottelson.[2] It is possible that the deviation may be attributed to a change in the intrinsic quadrupole moment for the higher states.

Sunyar succeeded in measuring the half-lives[22,23] of the 2+ states of Os^{190m} and Hf^{180m}, and in addition, with the help of a new delayed-coincidence technique,[24] also the considerably shorter half-lives of the 4+ states as given in Fig. 7. According to the strong coupling model,[2] the reduced transition probability for an $E2$ transition $(I+2\rightarrow I)$ between two states of a rotational band belonging to the ground state of an even-even nucleus is given by

$$B_e(2)=\frac{15}{32\pi}e^2Q_0^2\frac{(I+1)(I+2)}{(2I+3)(2I+5)}.$$

From this it follows that

$$B_e(2)(4+\rightarrow2+)/B_e(2)(2+\rightarrow0+)=10/7.$$

Sunyar's measurements make it possible for the first time to check this result:

	Hf^{180}	Os^{190}	Theor.
$\dfrac{B_e(2)(4+\rightarrow2+)}{B_e(2)(2+\rightarrow0+)}$	1.21±0.5	0.6±0.3	1.43

We see that there is satisfactory agreement with the theoretical value for Hf^{180}, but that the observed value for Os^{190} is appreciably lower. The result of this study is, then, that of the four differences noted earlier between Os^{190m} and Hf^{180m}, the first and second have been confirmed, the second even reinforced, whereas the third and fourth were shown to be nonexisting: Os^{190m}, just as Hf^{180m}, decays via an 8+ state, and both isomers have low energy, highly K-forbidden isomeric transitions. Alaga, Alder, Bohr, and Mottelson[13] have suggested, that the degree of K forbiddenness will depend on the value of $\Delta K-l$, where ΔK denotes the difference

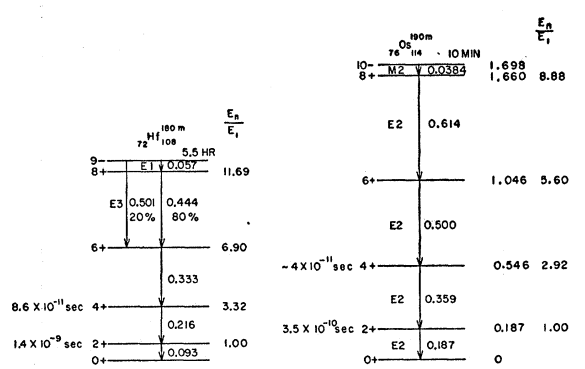

FIG. 7. Disintegration scheme of Os^{190m} in comparison with that of Hf^{180m}. The level energies of Os^{190m} are given in Mev and the column headed by E_n/E_1 on the right side of each scheme shows to what degree the proportionality with $I(I+1)$ holds in the two cases. A truly rotational level scheme would yield the following values for E_n/E_1: 3.33(I=4), 7.00(I=6), 12.00(I=8). The half-life of the 2+→0+ transition in Hf^{180} was reported by Sunyar,[23] who has also recently measured the other three half-lives.[22]

[23] A. W. Sunyar, Phys. Rev. **98**, 653 (1955).
[24] A. W. Sunyar, Bull. Am. Phys. Soc. Ser. II, **2**, 37 (1957).

TABLE II. The effect of the nuclear deformation on the validity of the K selection rule (dependence of $|M|^2$ on $\Delta K-l$) is presented. The isomeric transitions in Os^{190m} and in the strongly deformed nuclei Hf^{180m} [12] and Hf^{178m} [25] are compared.

	Os^{190m} ($\Delta K=10$)			Hf^{180m} ($\Delta K=9$)			Hf^{178m} ($\Delta K=9$)		
$\Delta K-l$	E_γ (kev)	Multipole order	$\|M\|^2$	E_γ (kev)	Multipole order	$\|M\|^2$	E_γ (kev)	Multipole order	$\|M\|^2$
8	38.4	$M2$	2.6×10^{-9}	57	$E1$	10^{-16}	88.8	$E1$	2.6×10^{-14}
6	652	$M4$	$<10^{-5}$	501	$E3$	10^{-9}			
4				834	$E5$	$<10^{-2}$			

of the quantum number K for the initial and final states of a transition and l the lowest multipole order of the transition. Table II compares $|M|^2$ for Os^{190m}, Hf^{178m},[25] and Hf^{180m} in terms of $\Delta K-l$. We see that for Os^{190m} the K selection rule is comparatively relaxed.

In conclusion, we may express the hope that the level scheme of Os^{190}, in combination with the knowledge of the matrix elements for the $4+\rightarrow2+$ and $2+\rightarrow0+$ transitions will encourage a theoretical study of "intermediate coupling" in nuclei.

B. DECAY OF Os^{189m}

Introduction

In addition to the 10-min Os^{190m} activity, Chu[9] found a 6-hr Os activity by "milking" Os from radioactive Ir obtained by both the $Os+d$ and the $Re+\alpha$ reactions. This activity was found to have an iridium mother with a half-life of several days, which was tentatively identified by Chu[9] with the 12-day Ir^{190} isomer, giving Os^{190} the rare distinction of triple isomerism. No detailed information on the radiation from this Os activity as obtained.

Experimental Procedure and Results

We were able to confirm the existence of the 6-hr Os activity, using the same production methods as Chu, and also the approximate half-life of the Ir mother. However, it was found that while the 10-min Os^{190m} is also produced by fast neutron bombardment of Ir^{191}, no 6-hr Os results from this process. Hence we concluded that the 6-hr activity must be Os^{189m}, following the decay of Ir^{189} (11 day), whose discovery was reported by Smith and Hollander.[26] A more accurate measurement of the half-life of Os^{189} yielded a value of 5.7 ± 0.1 hr.

The scintillation spectrum from this activity revealed only L x-rays, indicating a low-energy isomeric transition.

We searched for this transition using the intermediate image spectrometer with the same Geiger-counter window as was used for the study of the isomeric transition in Os^{190m}, and thus discovered the L, M, and N conversion lines from a 30.0-kev isomeric transition (Fig. 8). No other conversion electron line was found. From this spectrum we derived the intensity

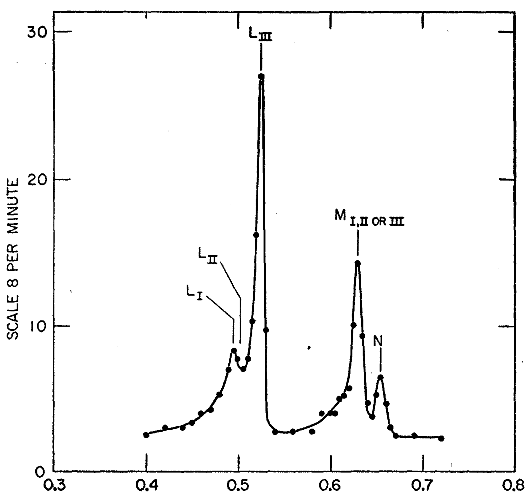

FIG. 8. Conversion electron spectrum of the 30.0-kev isomeric transition in Os^{189} (5.7 hr) taken at 1% resolution with intermediate image spectrometer. The sources used were electroplated on platinum foil from a carrier-free solution.

[25] F. Felber, University of California Radiation Laboratory Report UCRL-3618, 1956 (unpublished); M. Bunker and J. Mize, 1956 (private communication).

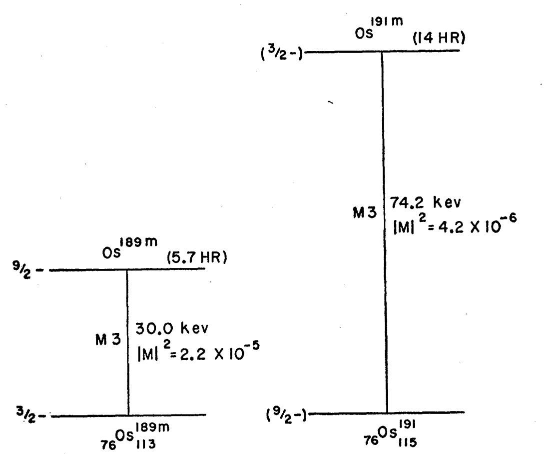

FIG. 9. The disintegration scheme of Os^{189m} is compared here with that of Os^{191m} as reported by Mihelich and Goldhaber.[28] Both isomers decay by $M3$ transitions, but in the less deformed Os^{191} the $3/2-$ level lies above the $9/2-$ (ground) state, whereas the reverse is true in Os^{189}, whose ground state was measured to be 3/2. The values for $|M|^2$ were obtained by comparing τ_γ—obtained by multiplying the measured mean life τ by $(1+\alpha)$, where α denotes the total conversion coefficient for an $M3$ transition[19]—with the theoretical single-particle lifetime given by Moszkowski.[21]

[26] W. G. Smith and J. M. Hollander, Phys. Rev. 98, 1258 (1955).

TABLE III. Comparison of measured $(L_{\mathrm{I}}+L_{\mathrm{II}})/L_{\mathrm{III}}$ and $M_{\mathrm{tot}}/L_{\mathrm{III}}$ ratios (see Fig. 8) with theoretical values[19] for 30.0-kev isomeric transition in Os^{189m} (5.7 hr). Each number in parentheses indicates the power of ten by which the preceding entry should be multiplied. The measured ratios indicate unambiguously that the transition is $M3$.

		Theoretical							
	Experimental	α_1	α_2	α_3	α_4	β_1	β_2	β_3	β_4
L_{I}		4.90(−1)	8.50(0)	6.40(+2)	2.10(+4)	2.60(+1)	1.60(+3)	4.00(+4)	7.00(+5)
L_{II}		4.00(−1)	3.90(+2)	3.80(+4)	1.20(+6)	2.15(0)	9.90(+1)	2.40(+3)	5.00(+4)
L_{III}		6.00(−1)	3.40(+2)	4.00(+4)	1.60(+6)	2.40(−1)	6.80(+2)	2.00(+5)	~1(+7)
M_{tot}					4.4(+6)			1.25(+5)	
$(L_{\mathrm{I}}+L_{\mathrm{II}})/L_{\mathrm{III}}$	0.25 ±0.05	1.48(0)	1.17(0)	9.65(−1)	7.63(−1)	1.18(+2)	2.50(0)	2.12(−1)	7.50(−2)
$M_{\mathrm{tot}}/L_{\mathrm{III}}$	0.53 ±0.10				2.74			0.62	
$N_{\mathrm{tot}}/L_{\mathrm{III}}$	0.154±0.025								
Unconverted γ-rays per transition	$<3\times10^{-4}$	3.3×10^{-1}	1×10^{-3}	1×10^{-5}	1.4×10^{-7}	2.6×10^{-2}	3×10^{-4}	2.6×10^{-6}	$\sim10^{-7}$
$\tau_{\frac{1}{2}}$(sec)	2.06×10^{4}						0.46		
$\lvert M\rvert^2$							2.2×10^{-5}		

ratios $(L_{\mathrm{I}}+L_{\mathrm{II}})/L_{\mathrm{III}}=0.25\pm0.05$, $M/L_{\mathrm{III}}=0.53\pm0.10$, and $N/L_{\mathrm{III}}=0.154\pm0.025$. Table III compares the relative intensities of the $(L_{\mathrm{I}}+L_{\mathrm{II}})$, L_{III}, and M lines with the theoretical values.[19] No 30-kev γ ray was found. An upper limit $I_{\gamma 30\ \mathrm{kev}}/I_{L\mathrm{x\text{-}rays}}<1/3000$ was deduced from the scintillation spectrum. Only an $M3$ assignment for the 30.0-kev transition is comparible with these data. Compared to a single neutron transition as given by Moszkowski,[21] $\lvert M\rvert^2$ for this $M3$ transition is 3.8×10^{-5}.

The spin of the ground state of Os^{189} has been measured to be 3/2[27]; hence we may assign a spin 9/2 to the isomeric state. According to the shell model (M. G. Mayer), a spin 3/2 state for 113 neutrons would be expected to be $p_{3/2}$; the isomeric state would then be $f_{9/2}$. From the point of view of the unified model, on the other hand, we have to assign to the ground state and isomeric state the characters 3/2- and 9/2- respectively, which indeed appear in this order in Nilsson's diagrams[6] for $\delta>0.18$. Figure 9 summarizes our results on Os^{189m} (5.7 hr).

It is interesting to compare this decay with that of Os^{191m} (14 hr)[28] whose isomeric transition is also $M3$. However, in this case the ground state probably has a 9/2− character, whereas the isomeric state is 3/2−. This, again, is in agreement with Nilsson's level scheme (in which the 9/2− state intersects the 3/2− state at $\delta\sim0.18$), if we assume that Os^{191} is less deformed than Os^{189}. From the regular trend of the levels of the even-even osmium nuclei with increasing neutron number, indicating a decrease in deformation, we may conclude that this is indeed the case. However, while the level scheme of Os^{190} indicates that this nucleus is only slightly deformed, Os^{189} still shows pronounced eccentricity.

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[27] K. Murakawa and S. Suwa, Phys. Rev. **87**, 1048 (1952); H. L. Loeliger and L. R. Sarles, Phys. Rev. **95**, 291 (1954).

[28] J. W. Mihelich and M. Goldhaber, Phys. Rev. **98**, 1185(A) (1955).

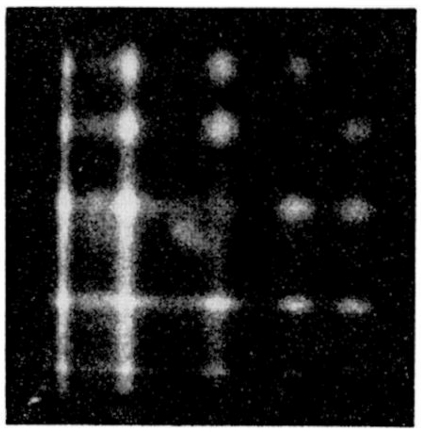

FIG. 3. Coincidence picture obtained from Ir^{190m} (3 hr), containing Os^{190m} (10 min) in equilibrium. The picture confirms the result of Aten *et al.*[10] that the four γ rays whose energies are given in Fig. 2 are in cascade. [The diagonal spot is due to the coincidence of two γ rays of 317 and 297 kev following the beta-decay of Ir^{192} (75 day), a small amount of which was present in the source.]