abundance or greater. The discrepancy between the abundance of the ~120-kev transition and the absence of a corresponding alpha-group is too close to the limits of error in measurement to be considered real at this stage. If it should prove to be real, this may be taken as evidence that the ground-state transition for the alpha-decay of Pu^{239} has not yet been seen.

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Radioisotopes of Osmium*

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Osmium activities of 15-day and 32-hour half-lives have been identified with Os^{191} and Os^{193}, respectively. A 14-hour activity, decaying by a 74.2-kev gamma-transition into the 15-day activity, has been assigned to an isomeric state in Os^{191}. The decay scheme of Os^{191} has been investigated and a 7/2+ assignment has been made to the 15-day ground state and an $i_{13/2}$ assignment to the 14-hour isomeric state. The 7/2+ state is attributed to a coupling of an odd number of $i_{13/2}$ neutrons.

INTRODUCTION

OSMIUM has seven stable isotopes, with mass numbers from 184 to 192, except for vacancies at 185 and 191. Three radioisotopes have so far been observed, and these have been allocated to mass numbers 185, 191 and 193.[1–13] We report in the present paper a new activity and a revised assignment of two of the already known activities.

Os^{191} AND Os^{191m}: EXPERIMENTAL OBSERVATIONS

Ordinary osmium, in powdered metallic form, was irradiated by neutrons in the heavy water pile at Argonne. The internal conversion electron spectrum, measured with 180° magnetic spectrographs, showed three groups of conversion lines. Accurate energy determinations, which are given in Table I, indicate that the gamma-transitions of 41.7 and 129.1 kev take place in iridium and that the 74.2-kev gamma-transition occurs in osmium.

Lifetime tests on the individual conversion lines showed that there was an initial rise in the intensity of the 41.7- and 129.1-kev lines, which changed over after a period of several days into a constant decay of 15-day half-life. On the other hand, the 74.2-kev transition lines decayed throughout with a half-life of 14±2 hours. A set of decay curves for a particular source, which was bombarded one day in a pile, is shown in Fig. 1. It is clear that the growth of the 41.7- and 129.1-kev transition intensities is consistent with a partial production of the 15-day activity from a parent of 14-hour half-life.

Osmium was also bombarded by gamma-rays from a 22-Mev betatron, using an internal target arrangement.[14] A conversion spectrum the same as, although weaker than, that from a pile irradiated source was obtained. The 15-day activity is therefore to be identified with mass number 191, instead of 193, and the 14-hour activity is thus an isomer of Os^{191}. The present assignment of the 15-day activity is in accord with beta-disintegration energy systematics, as pointed out by Way.[15,‡]

TABLE I. Energies in kev of electron conversion lines from Os^{191} and Os^{191m} activities.

Gamma-transition	Sub-shell origin of conversion electrons K	L_I	L_{II}	L_{III}	M_I	M_{II}	M_{III}	N
41.70 kev		···	28.85	30.48	···	38.80	39.19	41.15
74.17 kev		61.24	61.78	63.36	71.09	···	71.72	73.45
129.1 kev	53.15	115.49	116.14	117.97		126.29		128.76

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‡ *Note added in proof:*—A revision of the original Os^{191}, Os^{193} assignment by Seaborg and Friedlander (see reference 3) was later made by G. Friedlander (quoted in *Table of Isotopes*, Seaborg and Perlman, Revs. Modern Phys. **20**, 585 (1948)). According to J. M. Hollander (private communication) this revision was also made on the basis of γ-irradiations.

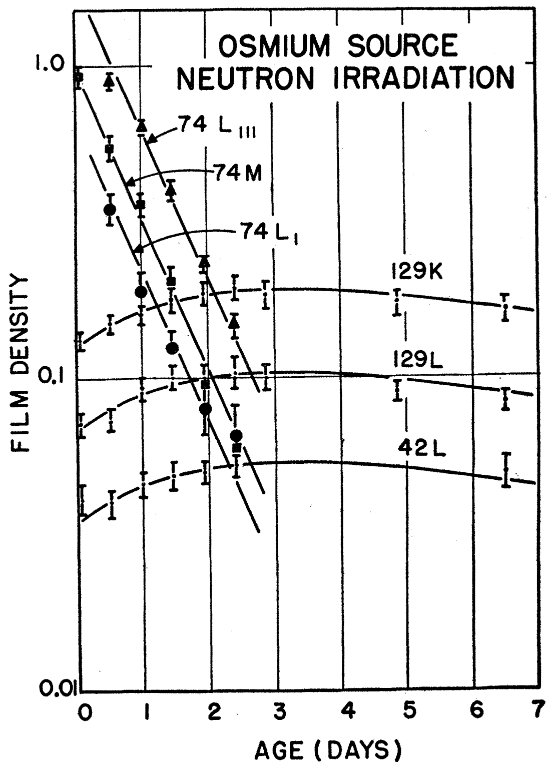

FIG. 1. Decay curves of conversion lines from the 74-kev gamma-transition of Os^{191m} and the 129- and 42-kev gamma-transitions of Os^{191}. Bombardment time of the source was one day. Zero time of the abscissa corresponds to the end of the bombardment.

In order to investigate whether there was any beta-decay associated with the 14-hour activity, an osmium source prepared by gamma-irradiation was studied using a lens spectrometer. The spectrum observed several hours after an 8-hour irradiation in the 22-Mev betatron is shown in Fig. 2. We conclude that direct beta-decay from the 14-hour isomeric level in Os does not occur to the extent of 5 percent, if at all, of the isomeric transition intensity from this level.

Investigations of the beta-spectrum of the 15-day Os^{191} activity were also made with lens and 180° spectrometers. However, our results, on account of the too-thick sources, did not lead to accurate values of the conversion coefficient of the 42- and 129-kev radiations. We are essentially in agreement with other workers[7,9,12] that there is a beta-spectrum with an upper end point in the neighborhood of 140 kev.

TABLE II. Relative intensities of conversion lines from Os^{191} and Os^{191m} activities.

Gamma-transition	K	L_I	L_{II}	L_{III}	M_I	M_{II}	M_{III}	N
	Sub-shell origin of conversion electrons							
41.70 kev		···	32	40	···	11	18.5	9.5
129.1 kev	100	29.5	10.5	6.0		11.5		3.5
74.17 kev		42	23.5	100	14	···	35	15

The 74.17-kev transition intensities are not directly comparable with the others.

An important question to be resolved in connection with the decay scheme of Os^{191} is whether the 42- and 129-kev transitions decay in cascade or parallel. Experiments to show whether gamma- or x-rays were or were not in coincidence were inconclusive. However, more elaborate experiments using a double slit 180° beta-ray spectrometer[16] showed that the 42-L and 129-L conversion electrons were definitely in coincidence.

The relative intensities of the 74.2- 41.7-, and 129.1-kev transition conversion lines were determined photographically and their values are given in Table II.

Os^{191}: DISCUSSION

The multipolarities of the 129.1- and 41.7-kev transitions have been obtained from the following arguments. Kondaiah's value[12] of the ratio of the L-conversion line intensity to the total Os^{191} beta-intensity, in conjunction with the conversion line intensities of Table II, yields a value of 1.36 for the K-conversion coefficient of the 129-kev transitions. Using Rose's tables,[17] this value is in best agreement with an 0.42:0.58 mixture of $M1$:$E2$ multipole radiations. Our value of 2.2 for the K/L ratio of the 129-kev transition agrees excellently with Kondaiah's value of 2.1, and using the empirical K/L ratios of Goldhaber and Sunyar,[18] the ratio of the $M1$:$E2$ mixture is 0.64:0.36. The ratios of the intensities of the L_I:L_{II}:L_{III} components of the 129-L conversion line, using Gellman's[19] unscreened theoretical L-shell conversion calculations, indicate an 0.8:0.2 mixture of $M1$:$E2$.

The multipolarity of the 42-kev transition is more difficult to obtain. Qualitatively, however, both our own scintillation counter experiments and photoelectron spectrometer studies of the 15-day Os^{191} show that the 42-kev transition is highly converted. Beta-conversion electron coincidence experiments[12] also show that the 42-kev gamma transition is certainly of multipole order less than three. One possibility of determining the multipolarity of this transition is through a comparison of theoretical and experimental L_I:L_{II}:L_{III} ratios. According to Gellman's analysis[19] these ratios are as follows: 1.0:0.68:1.0 for $E1$, 0.03:0.90:1.0 for $E2$, and 1.0:0.065:0.011 for $M1$. The experimental ratios are 0.0:0.81:1.0, which agree well with pure $E2$. An assignment of $M2$, for which there are no theoretical data, can be ruled out on beta- and gamma-transition considerations. The theoretical[19] total L-shell conversion coefficient of a 42-kev $E2$ transition is $\sim$200.

If we conclude that the 129-kev transition is a 3:1 mixture of $M1$:$E2$ and the 42-kev transition is pure $E2$, we find that the total intensity of the 129-kev

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transition is approximately twice the 42-kev transition intensity. Smaller mixtures of $M1$ in the 129-kev transition would necessarily increase the relative intensity of this transition.

Since it has been shown that the two transitions are in cascade it must be concluded that the 42-kev transition precedes the 129-kev transition. In this case, since the ground state Ir^{191} assignment[20] is $d_{3/2}$, the spins and parities of the 129.1- and 170.8-kev excited states are $5/2+$ and $9/2+$, respectively. The $5/2+$ assignment is in accord with a $d_{5/2}$ shell theory level, but there is no theoretical single-particle assignment for the $9/2+$ level.

The Os^{191} beta-transition of energy only 142 kev and half-life 15 days predicates an allowed transition. According to the cascade scheme proposed above, approximately equal intensity beta-branches would proceed to the 170.8-kev and 129.1-kev excited states. Both component spectra would necessarily be allowed, the lower energy component having $\log ft = 5.2$ and the higher energy component having $\log ft = 5.6$. The level assignment of the Os^{191} ground state would then be unequivocally $7/2+$.

Os^{191m}: DISCUSSION

The multipolarity of the 74.2-kev transition has been inferred from lifetime considerations. Probably the most uncertain factor in this analysis concerns the internal conversion coefficients, α_T, which influence the transition lifetimes, τ_γ, through the relationship, $\tau_\gamma = \tau_{\text{expt}}(1+\alpha_T)$. Estimates of the internal conversion coefficients have been obtained in the following way.

As the gamma-transition energy is just in excess of the K-shell binding energy (73.87 kev), estimates of the threshold K-shell conversion coefficients for a number of multipole radiations were obtained from the tables of Spinrad and Keller.[21] Very approximate estimates of the intense L-shell conversions were then obtained using the empirical values of the K/L ratios of Goldhaber and Sunyar.[18]

For $E3$ and $E4$ transitions, $\log_{10}(\tau_\gamma \rho^{2l})$ has the values of 9.4 and 11.6, respectively, and for $M3$ and $M4$ transitions, $\log_{10}(\tau_\gamma \rho^{2l-2})$ has the values 8.5 and 10.9, respectively. These values for $E3$ and $M3$ are approximately a factor 10^2 higher than the "average" observed values for a 74-kev transition of either of these multipoles.[18] For $E4$ and $M4$, the values are a factor of approximately 10^3 lower than the average observed values. This fact alone probably precludes an $M4$ assignment, since it is generally found that $M4$ transitions lie much closer than a factor of 10^3 to the average value.

As the Os^{191} ground state has been given a $7/2+$ assignment, and as the isomeric transition is very probably an octopole transition, it follows that the spin

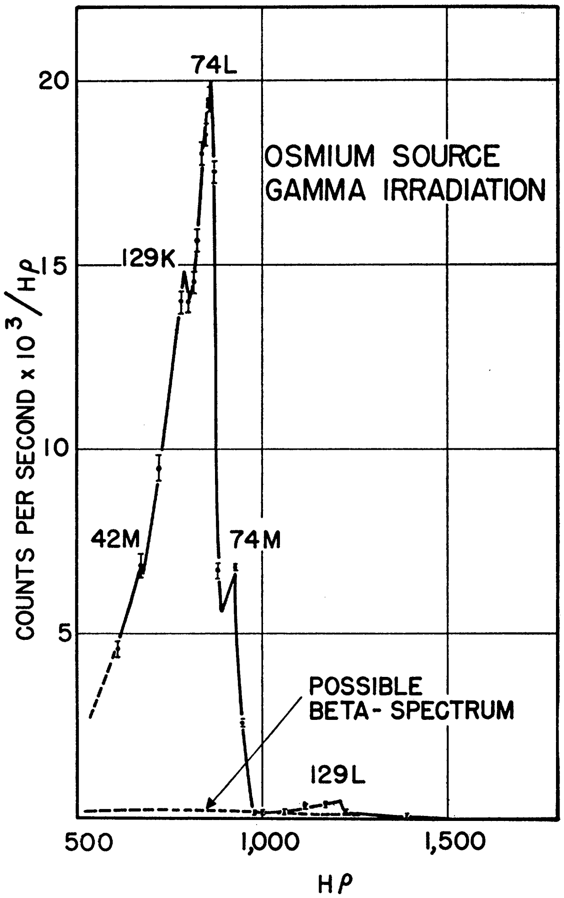

FIG. 2. Beta- and conversion-electron spectra of Os^{191m} and Os^{191}.

of the isomeric state is either 1/2 or 13/2. Of the four states having these spins, the even parity, 1/2 spin, state can be ruled out on the grounds of the absence of a direct beta-transition from Os^{191m} to the Ir^{191} ground state. Both the odd parity, 1/2 spin, and even parity, 13/2 spin, states are in accord with $p_{1/2}$ and $i_{13/2}$ levels of nuclear shell theory. An isomeric transition from a $p_{1/2}$ state would be $E3$, and from an $i_{13/2}$ state would be $M3$. A decision on whether this transition is $M3$ or $E3$ can be reached using the empirical L sub-shell conversion ratios determined by Mihelich.[22] For $M3$,

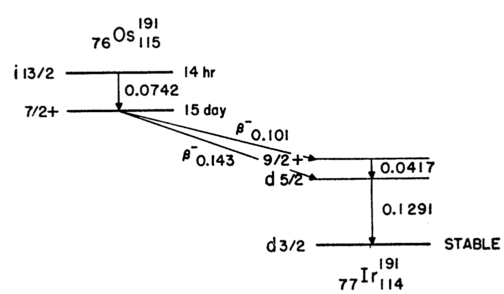

FIG. 3. Proposed decay scheme of Os^{191m} and Os^{191}.

[20] Brix, Kopfermann, and Siemens, Naturwiss. 37, 397 (1950); H. Kopfermann, Naturwiss. 38, 29 (1951).

[21] B. I. Spinrad and L. B. Keller, Phys. Rev. 84, 1056 (1951).

[22] J. W. Mihelich, Phys. Rev. 87, 646 (1952) and private communication.

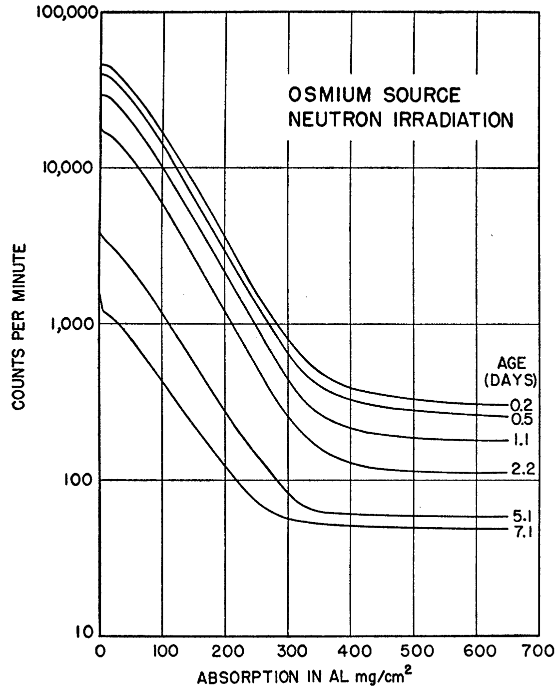

FIG. 4. Aluminum absorption curves of the radiations from a neutron-irradiated source of Os. These curves show the strong 1-Mev beta-component of Os^{193} which has an end point at approximately 350 mg/cm^2.

the expected L_{III} intensity is about twice the L_I intensity, whereas for $E3$, the L_{II} intensity appears to exceed the L_{III} intensity, with the L_I intensity very weak. The experimental L_I:L_{II}:L_{III} ratios therefore decide strongly in favor of $M3$. This assignment is shown in Fig. 3.

The existence of a $7/2+$ state in the region of Os^{191}, which has even Z and 115 neutrons, is not predicted by the independent particle nuclear shell theory. Odd neutron levels in this shell are $h_{9/2}$, $f_{7/2}$, $f_{5/2}$, $p_{3/2}$, $p_{1/2}$, and $i_{13/2}$. As an odd number of neutrons can lead to an even parity state only if they are of even parity, the $7/2+$ state is therefore attributed to a coupling of an odd number of $i_{13/2}$ neutrons or possibly a coupling of an $i_{13/2}$ neutron with the nuclear core.

There are two other examples[23] of $7/2+$ levels in this region. W^{183} and W^{185}, with $N=109$ and 111, respectively, exhibit $7/2+$ isomeric states. It was pointed out that these states were anomalous, and it now seems reasonable that they may also arise from a coupling of an odd number of $i_{13/2}$ neutrons.

Systematics of isomer levels[23,24] indicate that $p_{1/2}$ levels are energetically close to $i_{13/2}$ levels in the region of $N=117$. In fact, extrapolation of level trends indicates that the $i_{13/2}$ levels might lie lowest in the region of Os^{191}.

[23] M. Goldhaber and R. D. Hill, Revs. Modern Phys. 24, 179 (1952).

[24] R. D. Hill, Brookhaven Quarterly Report 11, 18 (1951) (unpublished).

Os^{193}: OBSERVATIONS AND DISCUSSION

The identification of the 32-hour beta-activity as Os^{193} was made on the basis of lifetime and absorption measurements. Osmium sources obtained from pile irradiations exhibited a strong 32-hour beta-activity, and aluminum absorption curves indicated a predominant 1-Mev beta-component which decayed with this half-life. Curves showing the decay of the 1-Mev component are given in Figs. 4 and 5. Osmium sources from betatron irradiations showed an initial decay of 14 hours half-life, with no 32-hour activity observable. Absorption curves also gave no indication of the 1-Mev beta-component associated with the 32-hour activity. Curves showing the decay of the Os^{191} radiations are given in Fig. 6.

In the pile irradiated sources several very weak conversion lines were observed to decay with half-lives intermediate between 14 hours and 15 days. The gamma-transitions identified from K and L conversion lines were of energies 215, 323, and 460 kev. There were also weak intensity lines of 55.2, 59.4, 60.0, and 67.2 kev. The 59.4- and 60.0-kev lines appear to be L_I and L_{II} conversion lines of a 72.4-kev gamma-transition. Some or all of these transitions could have half-lives consistent with 32 hours.

Gamma-transitions associated with the 32-hour activity have been reported previously[4,8,10] at energies

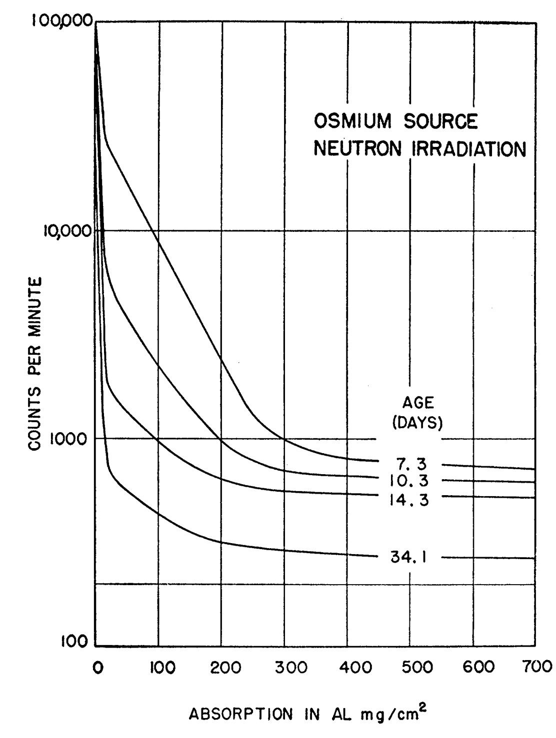

FIG. 5. Aluminum absorption curves of radiations from a neutron-irradiated source of Os. These curves were taken at later times and with the source closer to the counter than in the case of Fig. 4. The curves illustrate the disappearance of the Os^{193} beta-component, as well as the increasing similarity with the curves of Fig. 6, as the Os source ages.

of 1.58, 1.17, 0.22, and 0.065 Mev. If the 59.4- and 60.0-kev conversion lines are to be identified with the 65-kev transition observed in delayed-coincidence by McGowan,[10] then it must be concluded that this transition is only very weak compared with the beta-intensity of Os^{193}. McGowan has identified the 65-kev transition as $E2$. According to Gellman *et al.*[19] the total L conversion of such a transition is approximately nineteen. From the measured intensity of the 59.4- and 60.0-kev lines relative to the intensity of the 32-hour beta-spectrum, we conclude that the "65-kev" transition occurs to the extent of less than 2 percent of the beta-decays from Os^{193}.

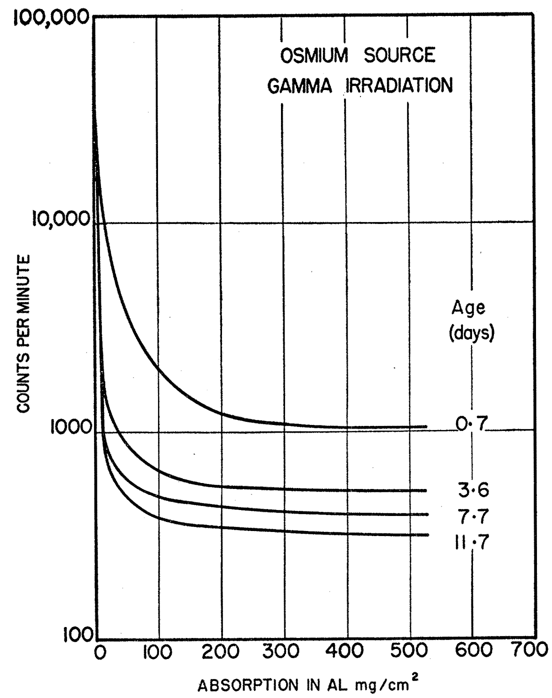

FIG. 6. Aluminum absorption curves of radiations from a gamma-irradiated source of Os. These curves show an electron component of end point approximately 20 mg/cm² which is characteristic of Os^{191}.

TABLE III. Internal conversion lines of long half-lives from neutron-irradiated osmium.

Energy (kev)	Interpretation	γ-energy (kev)	Activity
152	γ_1-L in Re	164	?
160	γ_1-M in Re	163	?
163	γ_2-K in Re	235	?
223	γ_2-L in Re	235	?
231	γ_2-M in Re	234	?
219	γ_3-K in Pt	297	Ir^{192}
284	γ_3-L in Pt	297	Ir^{192}
296	γ_3-M in Pt	299	Ir^{192}
231	γ_4-K in Pt	309	Ir^{192}
296	γ_4-L in Pt	309	Ir^{192}
304	γ_4-M in Pt	307	Ir^{192}
240	γ_5-K in Pt	318	Ir^{192}
304	γ_5-L in Pt	317	Ir^{192}
312	γ_5-M in Pt	315	Ir^{192}
391	γ_6-K in Pt	469	Ir^{192}
456	γ_6-L in Pt	469	Ir^{192}
580	γ_7-K in Re	652	Os^{185}
641	γ_7-L in Re	653	Os^{185}
653	γ_7-M in Re	656	Os^{185}

Os^{185}: OBSERVATIONS

A two-month old neutron-irradiated Os source was examined in a lens spectrometer and conversion lines corresponding to previously reported[9,25] transitions of 0.65 and 0.88 Mev were observed. Prolonged exposures of the same source in 180° magnetic spectrographs brought out a number of conversion lines of weak intensities and also of long half-lives. An attempt has been made to analyze and identify these lines in Table III.

[25] M. M. Miller and R. G. Wilkinson, Phys. Rev. **82**, 981 (1951).