present information, particularly when it is considered that the scattering was in the neighborhood of 90° in the CM system.

The authors wish to express their gratitude to Professor J. R. Richardson for his suggestions and to thank Mr. S. Plunkett and Mr. G. Jones of the Cyclotron Laboratory and Mr. E. Griffiths and his staff in the Physics Department Shop for their aid in building and setting up the apparatus. The Eastman Kodak Company very kindly supplied the special film required.

PHYSICAL REVIEW VOLUME 79, NUMBER 4 AUGUST 15, 1950

# New Radioactive Isotopes of Iridium*

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(Received April 24, 1950)

Four new isotopes of iridium have been prepared by bombarding isotope-enriched rhenium as well as natural rhenium with alpha-particles, and osmium with deuterons. Three of them have been identified as follows:

| Isotope | Half-life | Type of radiation | Energy of radiation (Mev) Particle | $\gamma$-rays | Produced by |
|---|---|---|---|---|---|
| $Ir^{187}$ | 11.8 hr. | $K\beta^+e^-\gamma$ | $\beta^+$ 2.2<br>$e^-$ 0.28, 1.2 | *L*, *K* x-rays<br>1.3 | $Re(\alpha, 2n)$<br>$Re^{185}(\alpha, 2n)$<br>$Os(d, 3n)$ |
| $Ir^{188}$ | 41.5 hr. | $K\beta^+e^-\gamma$ | $\beta^+$ 2.0<br>$e^-$ 0.16, 0.85 | *L*, *K* x-rays<br>1.8 | $Re(\alpha, n)$, $(\alpha, 3n)$<br>$Re^{187}(\alpha, 3n)$<br>$Os(d, 2n)$, $(d, 3n)$ |
| $Ir^{190}$ | 3.2 hr. | $K(?)\beta^+e^-\gamma$ | $\beta^+$ 1.7<br>$e^-$ 0.2, 0.8 | — | $Re(\alpha, n)$<br>$Re^{187}(\alpha, n)$<br>$Os(d, n)$, $(d, 2n)$ |

The 3.2-hr. period is an isomer of the 12.6-day $Ir^{190}$.

Another weak activity, possibly $Ir^{189}$, of more than 100-day half-life has been observed.

Four daughter activities of iridium (9.5-min., 6-hr., 35-hr. and *ca.* 50-day radio osmium) have been found, and their possible genetic relations discussed.

A rhenium activity of *ca.* 1-hr. half-life has been noticed in the Os+19-Mev deuteron experiment.

## I. INTRODUCTION

The previous work on this element, iridium, has resulted in the observation of a number of radioactive isotopes.[1] However, on the neutron deficient side of the stable isotopes only one period has been reported.[2] The isotope chart shows that the following mass numbers of Ir (186, 187, 188, 189 and 190) can be produced by $(\alpha, n)$, $(\alpha, 2n)$, and $(\alpha, 3n)$ reactions on rhenium, which has two stable isotopes, $Re^{185}$ and $Re^{187}$, of relative abundance 37.07 and 62.93 percent respectively. Using the 60-in. cyclotron at the Crocker Laboratory, this attractive field was investigated. Enriched rhenium isotopes and spongy osmium were also used in confirmatory work concerning the reactions and the mass assignments of the products. (See Table I.)

Table I. Isotopic compositions of rhenium samples.

| Isotope | Natural rhenium | "Re 185"* | "Re 187"* |
|---|---|---|---|
| | percent | percent | percent |
| 185 | 37.07 | 85.38 | 1.78 |
| 187 | 62.93 | 14.62 | 98.22 |

* Obtained from Carbide and Carbon Company, Chemistry Division, Oak Ridge, Tennessee.

## II. EXPERIMENTAL

Bombardments of rhenium with 38-Mev helium ions and of osmium with 19-Mev deuterons were made in the 60-in. cyclotron. Metallic rhenium powder (100 mg) was mounted on a copper target plate and covered with 0.2-mil tantalum foil. In the case of osmium, samples of the spongy metal were bombarded on a water-cooled platinum interceptor, also using 0.2-mil Ta foil to protect the powder. Experiments with low energy $\alpha$-particles were made by placing a suitable thickness of Ta foil over the target to act as an absorber. (Calculated from the range-energy chart for $\alpha$'s drawn from the data of Aron, Hoffman and Williams.)

After bombardment, the rhenium target was dissolved in dilute nitric acid, and the osmium in aqua regia, in an all-glass distilling flask. Chemical separations were made after the addition of the proper inactive carriers. Osmium was separated by distillation of the volatile tetroxide followed by precipitation of the sulfide with sodium thiosulfate. The mother liquor was evaporated to dryness and then taken up with water. Iridium was reduced to the metal by formic acid in hot solution. After removal of these elements, rhenium was

* This work was performed under the auspices of the AEC.
† On leave from Institute of Chemistry, Academia Sinica, China.
[1] G. T. Seaborg and I. Perlman, Rev. Mod. Phys. **20**, 585 (1948).
[2] L. J. Goodman and M. L. Pool, Phys. Rev. **70**, 112 (1946); **71**, 288 (1947).

finally precipitated as the sulfide with sodium thiosulfate.

"End on" type argon-ethanol filled Geiger counters with approximately 3 mg/cm$^2$ mica windows were used throughout the experiment. Coincidence and geometrical corrections have been applied to all the counts. Variations in counter efficiency were checked by a $UX_2$ standard. A beta-ray spectrometer of low resolving power was used to differentiate the positrons and the beta-particles.

Radiation characteristics were studied by using beryllium, aluminum and lead absorbers. Electron and soft electromagnetic radiations were distinguished by their differential absorption in aluminum and beryllium.[3] The average energy of $L$ x-rays in this region is of the order of 9 kev with an absorption half-thickness in beryllium of 700 mg/cm$^2$. For the lead absorption, lead screens were used with beryllium absorbers, placed below and above the lead, of sufficient thickness to remove all the electrons from the sample and the secondary electrons emitted from the lead, respectively.

The ratios of electrons and the electromagnetic radiations were determined with due corrections for counter window and air gap absorptions of electrons as well as for counting efficiencies of quantum radiations. Thus, for the $L$ x-rays a counting efficiency of 5 percent was assumed, for $\gamma$-rays from 20 kev to less than 500 kev, 0.5 percent, from 500 kev to 1 Mev, one percent, etc. Cross sections were calculated for thin samples. The total beam current to the target was integrated by the cyclotron instruments. In these calculations the relative values should be more correct than the absolute values.

## III. RESULTS

Four half-lives, 3.2±0.2 hr., 11.8±0.3 hr., 41.5±0.5 hr. and 12.6±0.3 day were observed in the iridium fraction separated from rhenium bombarded with 30-Mev helium ions. The first three isotopes emitted positive electrons (Fig. 1). A 19-Mev deuteron bombardment on osmium gave the above-mentioned activities and the well-known 75-day $Ir^{192}$ as the major product.

One additional weak period of more than 100 days was observed in the iridium fraction from rhenium bombarded with approximately 40-Mev $\alpha$-particles in the 184-in. cyclotron, but it was not studied in detail.

The relative yields of the activities obtained by varying the energy of the impinging alpha-particles are shown in Table II and Fig. 2.

### 11.8-Hr. $Ir^{187}$

In Fig. 2 it is seen that the yield of this activity increases with increasing alpha-energy in the bombardment of natural rhenium. From this and the results of the experiments with enriched rhenium isotopes, this period was assigned to $Ir^{187}$ with confidence. The increasing trend of the yield curve might be explained by assuming the possible contribution of an $(\alpha, 4n)$ reaction in the 38- to 40-Mev alpha-range, where it is usually acknowledged that the $(\alpha, 3n)$ reaction should play the principal role.

From gross and differential decay its half-life was found to be 11.8±0.3 hr. Magnetic counter readings both from Re+$\alpha$ and Os+$d$ sources indicated the presence of positrons (Fig. 1).

A satisfactory characterization of the radiations by absorption measurements was not obtained, since its measured activity was too close to that of the 41.5-hr. period. However, a group of harder electrons with a maximum energy of 1.2 Mev and a softer group of 0.28 Mev were found both from absorption measurements and from beta-ray spectrometer readings of the iridium

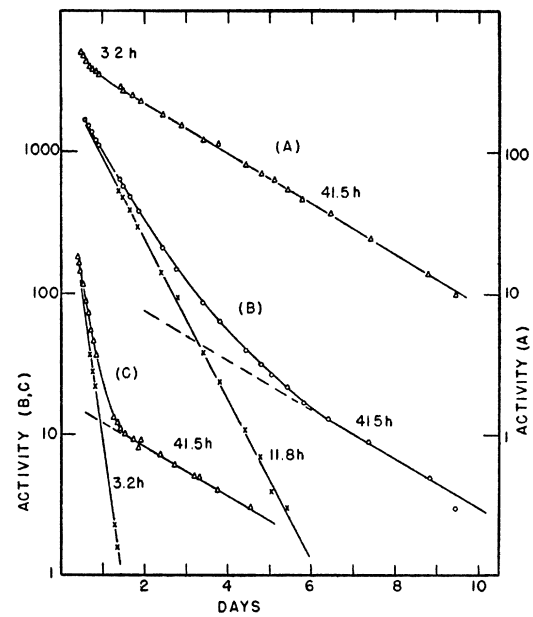


FIG. 1. Decay of positrons of radioactive iridium. (A) 41.5-hr. $Ir^{188}$ from enriched "Re 187"+32-Mev $\alpha$-particles. (B) 11.8-hr. $Ir^{187}$ and 41.5-hr. $Ir^{188}$ from "Re 185"+32-Mev $\alpha$. (C) 3.2-hr. $Ir^{190}$ and 41.5-hr. $Ir^{188}$ from "Re 187"+22-Mev $\alpha$.

TABLE II. Relative yields of the radioiridium at various $\alpha$-energies.

| Sample | Impinging $\alpha$-energy | 3.2 hr. | 11.8 hr. | 41.5 hr. | 12.6 day |
|---|---|---|---|---|---|
| Natural | 21 Mev | 14.8 | 5.9 | 36.2 | 43.0 |
| Rhenium | 25 | 9.0 | 27.0 | 22.8 | 41.3 |
| | ~30 | 11.0 | 27.9 | 25.2 | 35.9 |
| | 38 | 3.0 | 38.2 | 42.5 | 16.2 |
| | ~40 | 2.5 | 41.5 | 43.7 | 12.2 |
| Enriched | 22 Mev | 9.8 | 3.1 | 25.8 | 61.2 |
| "Re 187" | 32 | 2.2 | — | 78.7 | 19.0 |
| "Re 185" | 32 Mev | — | 84.4 | 13.7 | 1.8 |

[3] G. Wilkinson, Phys. Rev. 75, 1019 (1949).

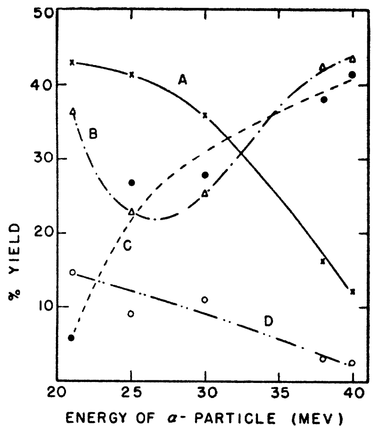


FIG. 2. Relative yields of the radioactive iridium from Re+$\alpha$ particles. (A) 12.6-day $Ir^{190}$. (B) 41.5-hr. $Ir^{188}$. (C) 11.8-hr. $Ir^{187}$. (D) 3.2-hr. $Ir^{190}$.

fraction isolated from the bombardments of the enriched $Re^{185}$ target (Figs. 3 and 4(I)). The beta-ray spectrometer record was taken at an early stage when this activity was present predominantly. It shows that the positrons (curve A) had a maximum energy of 2.2 Mev and a mean energy of approximately 0.7 Mev. Since the $\beta^+$/electron capture branching ratio is small, their maximum energy was not determined by aluminum absorption. Any such contribution from $\beta^+$ would be buried in the strong electromagnetic background, which showed components with half-thicknesses in lead of 150 mg/cm², corresponding to 63 kev, and 12.5 g/cm², approximately 1.3 Mev. The former corresponds well with the osmium $K$ x-rays. The $L$ x-rays of half-thickness 24 mg/cm² aluminum, corresponded to about 9 kev.

An approximate ratio of positive and negative electrons and electromagnetic radiations was obtained from absorption measurements, the usual corrections for counter window, counting efficiencies, etc., being considered.

$$\begin{array}{ccccccccccc} 0.28 \text{ Mev } e_1 & : & 1.2 \text{ Mev } e_2 & : & 2.2 \text{ Mev } \beta^+ & : & L \text{ x-rays} & : & K \text{ x-rays} & : & 1.3 \text{ Mev } \gamma = \\ 0.22 & : & 0.025 & : & 0.002 & : & 0.62 & : & 1 & : & 0.75 \end{array}$$

The ratio of $L$ x-radiation to $K$ x-rays is comparatively higher than those of other periods studied; this, and also the high yield of electrons seemed to suggest the possibility of some $L$ electron captures, and of course, the possibility of a $\gamma$-ray of this energy accounting for the excess of $L$ x-rays cannot be excluded. Assuming that one $K$ x-ray represents one disintegration by orbital electron capture, about 0.2 percent of the disintegrations of this activity occurs by positron emission.

### 41.5-Hr. $Ir^{188}$

This isotope was produced both from $\alpha$-bombardment on rhenium and from deuteron bombardment on osmium. A study of its yield from natural rhenium targets justifies postulating its formation by an $(\alpha, n)$ reaction on $Re^{185}$ and an $(\alpha, 3n)$ reaction on $Re^{187}$.

Gross and differential decay measurements give 41.5 hr. as its half-life. The aluminum absorption curve (Fig. 5) which has been corrected for the contributions of the 12.6-day $Ir^{190}$ and the 41.5-hr. $L$ x-rays, 9 kev, shows at least three components. A hard one has an end point at 300 mg/cm² corresponding to a maximum energy of 0.85 Mev according to Feather's formula, a soft one has a range of 25 mg/cm² or an energy of 0.16 Mev, and a still harder particle of an approximate range of 900 mg/cm², approximately 2 Mev.

Beta-ray spectrometric examination showed also the existence of positrons. The momentum distribution curve (Fig. 4(II)) shows the end point corresponding to 2 Mev and a mean energy of approximately 0.5 Mev. Curve B of Fig. 4(II) stands for the negative electron distribution, with end point of the harder group corresponding to a maximum energy of 0.85 Mev and an average of 0.3 Mev, and the lower energy peak corresponded to 0.16 Mev for its softer group. All check very well with the aluminum absorption measurements.

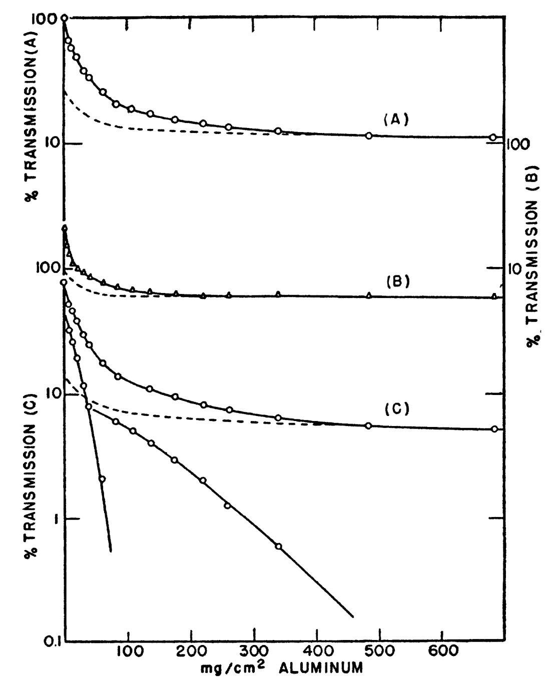


FIG. 3. Aluminum absorption of 11.8-hr. $Ir^{187}$ and 41.5-hr. $Ir^{188}$ from "Re 185"+$\alpha$. (A) Measured curve for mixed activities. (B) Contribution of the 41.5-hr. activity at the time when (A) was taken. (C) Resolved absorption of 11.8-hr. $Ir^{187}$.

The soft part probably represents a single conversion electron, while the broader one may be a mixture of several conversion electrons.

In Fig. 5 is also shown the lead absorption of the electromagnetic radiations. The soft component has a half-thickness of 145 mg/cm² corresponding to 62 kev, which is quite an acceptable value for osmium $K$ x-rays. The gamma-ray has a half-thickness of 15 g/cm² corresponding to 1.8 Mev.

The ratios of the various radiations were obtained from aluminum and lead absorption measurements as follows:

$$0.16 \text{ Mev } e_1 : 0.85 \text{ Mev } e_2 : 2 \text{ Mev } \beta^+ : L \text{ x-rays} : K \text{ x-rays} : 1.8 \text{ Mev } \gamma = 0.08 : 0.007 : 0.003 : 0.21 : 1 : 0.55$$

Assuming that some of the $K$ x-rays arise from production of the conversion electrons, then from the above ratio, approximately 90 percent of the $K$ x-rays must arise from orbital electron capture, and hence it is assumed that 0.90 $K$ x-ray represents one disintegration. The branching ratio for the positron disintegration is approximately 0.3 percent.

### 3.2-Hr. $Ir^{190}$

In the course of this work the 3.2±0.2 hr. positron emitter was always found in small quantities both in the Re+$\alpha$ and Os+$d$ reactions. The possibility of its being an impurity received first attention. Spectroscopic analysis of one of the natural rhenium samples showed only a trace of silicon present (0.01 to 0.1 percent), and any other impurities would not exceed this amount. Chemical separation proved it to be an iridium activity, and in several later experiments including those with enriched $Re^{187}$, it was present in amount greater than 10 percent of the total iridium activity.

From the results of the magnetic counter measurements (Fig. 4(III)), the positive electron has a maximum energy of 1.7 Mev and a mean value of approximately 0.6 Mev. The spectrum of the negative electron is complex and consists of at least two groups. A line of conversion electron appeared at $H\rho = 1570$ gauss-cm corresponding to 0.2 Mev. The harder group has a maximum energy of 0.8 Mev and a mean value of 0.25 Mev. On account of the relatively strong intensities of both the 11.8-hr. and 41.5-hr. isotopes which occurred with this activity, the aluminum absorption curve (Fig. 6) is not resolved, but suggests that the mixed positive and negative electrons have a maximum range of energy of 1.8 Mev and a softer group of approximately 0.2 Mev. Even more trouble was encountered with the $\gamma$'s.

Of these three positron emitting activities of iridium, this one must have the largest $\beta^+$ to electron capture branching ratio.

### 12.6-Day $Ir^{190}$

Goodman and Pool[2] have already assigned to $Ir^{190}$ a 10.7-day activity obtained from deuteron bombardment of Os and from an $(n, 2n)$ reaction on Ir. In this experiment it was also produced by an $(\alpha, n)$ reaction on Re. Enriched $Re^{187}$ produced more than 10 times the amount of this activity as the enriched $Re^{185}$ when both were subjected to 32-Mev $\alpha$-bombardment. The assignment of this period to $Ir^{190}$ is therefore well-confirmed. The best value for its half-life, followed through nine half-lives, is 12.6±0.3 days.

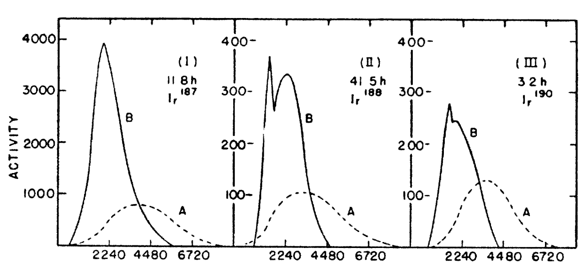


FIG. 4. The beta-spectra of the iridium isotopes. (A) Positrons. (B) Electrons. (I) 11.8-hr. $Ir^{187}$; (II) 41.5-hr. $Ir^{188}$; (III) 3.2-hr. $Ir^{190}$.

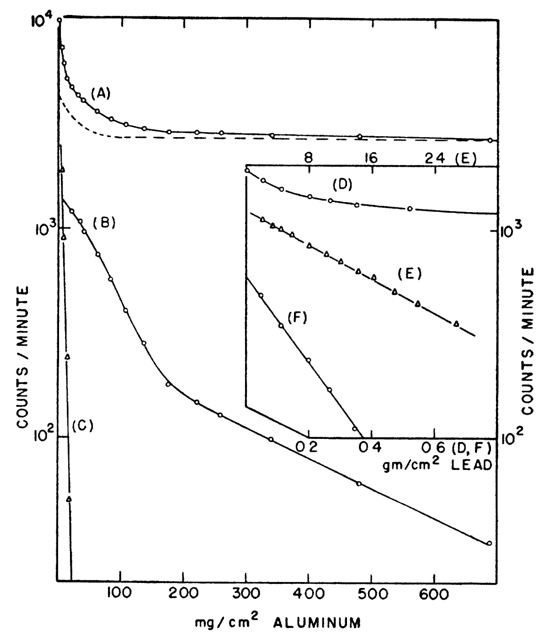


FIG. 5. Absorption curves for 41.5-hr. $Ir^{188}$. (A) Measured curve in aluminum, with $L$ x-ray, $K$ x-ray, and $\gamma$-ray background. (B) Positrons and hard electrons. (C) Soft electrons. (D) and (E) The first and second halves of the measured curve in lead, drawn in different scale, showing hard $\gamma$-ray of 15 gm/cm² half-thickness. (F) $K$ x-ray, half-thickness 145 mg/cm².

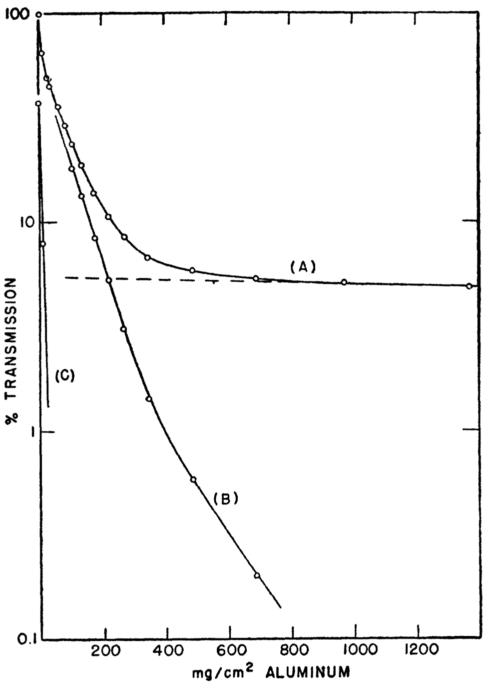


FIG. 6. Aluminum absorption of 3.2-hr. $Ir^{190}$ and 41.5-hr. $Ir^{188}$. (A) Measured at 2 hr. after bombardment. (B) Positrons and hard electrons. (C) Soft electrons.

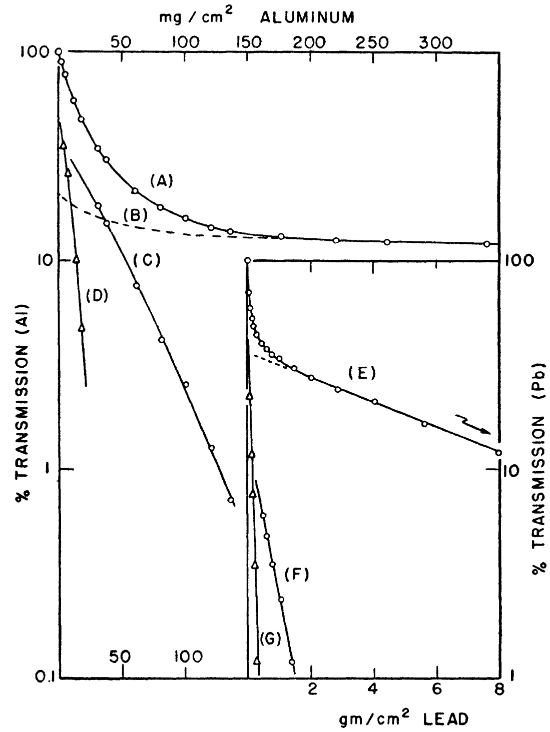


FIG. 7. Absorption curves of 12.6-day $Ir^{190}$. (A) Aluminum absorption curve. (B) $L$ x-ray. (C) Hard electrons. (D) Soft electrons. (E) Lead absorption curve and the hard $\gamma$-ray. (F) Soft $\gamma$-ray. (G) $K$ x-ray.

The aluminum absorption curve in Fig. 7, shows for the soft and hard groups of electrons, after correction for $L$ x-rays, energies of 0.17 Mev and 0.5 Mev respectively. The absorption curve obtained from the Os+$d$ experiment, after deducting the contributions from the 75-day Ir, revealed the same characteristics. This is a little different from what Goodman and Pool have observed. The $\gamma$-rays of half-thicknesses of 400 mg/cm² lead, corresponding to 0.17 Mev, and of 5.2 g/cm² lead, corresponding to 0.55 Mev, were clearly disclosed by lead absorbers (Fig. 7). The $K$ x-rays were not definitely observed, the radiation resolved from soft and hard $\gamma$-quanta showing a half-thickness of only 80 mg/cm² lead. A stronger sample would probably give better results.

However, an estimate of the approximate ratios of radiations, with proper allowances for various assumptions, was made as follows:

$$\begin{array}{ccccccccccc} 0.17\text{ Mev } e_1 & : & 0.5\text{ Mev } e_2 & : & L\text{ x-rays} & : & K\text{ x-rays} & : & 0.17\text{ Mev } \gamma_1 & : & 0.55\text{ Mev } \gamma_2 = \\ 0.07 & : & 0.04 & : & 0.15 & : & 1 & : & 0.45 & : & 0.42 \end{array}$$

Assuming that $K$ x-radiation also arises from the process of conversion, then about 0.85 $K$ x-ray will represent one disintegration by orbital electron capture.

## OSMIUM DAUGHTERS

Four low activities of osmium, 9.5 min., 6 hr., approximately 35 hr. and approximately 50 day, were obtained from "milking" experiments on mixed artificial radioactive iridium. They were also observed in the osmium fraction separated directly from rhenium targets. In some instances the well-known 95-day osmium was found to be present in the direct separations.

The 9.5-min. period was present in every direct separation, but appeared only in the early milkings. In one sample from an Os+deuteron bombardment, the milking process was carried out from time to time covering a period of 35 days. The 9.5-min. activity disappeared after one day, the 35-hr. disappeared after a week, the 50-day after 17 days, while the 6-hr. period lasted throughout. Based on the interval of separation and relative number of atoms of growth and decay, the 9.5-min. osmium was found to be the daughter of 3.2-hr. $Ir^{190}$. The 35-hr. Os and 6-hr. Os are possibly related to the 11.8-hr. $Ir^{187}$ and the 12.6-day $Ir^{190}$ respectively. The 50-day osmium was very weak, but it was definitely distinguishable from the 95-day Os. In the first place, the Ir activities used for milking were reduced after the mother liquor had been evaporated to dryness, expelling osmium activity which might remain in the mother liquor. Secondly, the gross decay curve of one of the direct separations has revealed the co-existence of the approximately 50-day and the 95-day periods.

The radiations of these activities have not been successfully studied. For the 9.5-min. period, the aluminum absorption curve give a maximum energy of 0.5 Mev, indicating the mixed energy of soft electromagnetic radiation and electrons (factor of decay being corrected) (Fig. 8). An aluminum absorption curve for the 6-hr. Os is also shown in Fig. 8.

No positrons were detected from one comparatively strong sample of these osmium activities.

### OTHER ACTIVITIES

#### (1) 75-Day $Ir^{192}$

In the bombardment of osmium with deuterons there was a very good yield of the well-known $Ir^{192}$. The best value for its half-life is 74.7 days. The electron range in aluminum has a maximum value of 0.68 Mev according to Feather's method, and the gamma-energy from lead absorption is 0.42 Mev.

#### (2) 95-Day $Os^{185}$

The irradiation of rhenium with deuterons led to the production of the 95-day Os. It was also observed in minute quantities in the rhenium$+\alpha$, and osmium$+d$ bombardments. Its radiation characteristics were found to agree with those given by Katzin and Pobereskin.[4]

#### (3) 16-Day $Os^{191}$; 30.6-Hr. $Os^{193}$

These isotopes were observed as the products of $(d, p)$ reactions on osmium. The best half-life for $Os^{191}$, after subtracting the contributions from the long-lived 95-day isotope is $16.0\pm0.3$ days, and that for $Os^{193}$ is $30.6\pm0.4$ hr. The absorption curve of the 16-day Os with correction for $L$ x-rays, showed a weak conversion electron of 0.15 Mev in aluminum, and the gamma in lead corresponded to 0.14 Mev. These data are consistent with Katzin and Pobereskin's[4] and Saxon's[5] measurements. The aluminum absorption curve of the 30.6-hr $\beta$-emitter showed an end point of 440 mg/cm$^2$ corresponding to 1.15 Mev as was found by Mandeville *et al.*[6]

#### (4) 90-Hr. $Re^{186}$; 17-Hr. $Re^{188}$

These well-established isotopes were formed by $(d, p)$ reactions on rhenium in proportion very close to the natural abundance ratio of $Re^{185}$ and $Re^{187}$. The $\beta$-particles of $Re^{186}$ showed a range in aluminum corresponding to 0.96 Mev, and that of $Re^{188}$ corresponded to 2.2 Mev.

[4] L. I. Katzin and M. Pobereskin, Phys. Rev. **74**, 264 (1948).
[5] D. Saxon, Phys. Rev. **74**, 1264 (1948).
[6] Mandeville, Scherb, and Keighton, Phys. Rev. **74**, 888 (1948).

They were also observed in the Re fraction from Re$+\alpha$-bombardment, especially when the $\alpha$-energy was below the threshold of $(\alpha, n)$ reaction. This is another instance of the large neutron cross section of rhenium.[7]

#### (5) 1-Hr. Re

In the experiment with Os$+d$ (19 Mev), an activity of approximately 1-hr. half-life was noticed in the rhenium fraction. If it is not due to an impurity, it may probably be the product of a $(d, \alpha)$ reaction.

### IV. DISCUSSION

From the curves of relative yields shown in Fig. 2, it seems quite probable to assign the 41.5-hr. period to $Ir^{188}$, the 11.8-hr. period either to $Ir^{187}$ or to $Ir^{189}$, and the 3.2-hr. period as an isomer of the 12.6-day $Ir^{190}$.

The assignment of the 41.5 hr. to $Ir^{188}$ was rather obvious considering its yield from natural rhenium which has two stable isotopes, 185 and 187, of relative abundance 37.07 and 62.93 percent, respectively. The predominance at lower energy $\alpha$-bombardments of the $(\alpha, n)$ reaction on the 185 isotope, and at higher energies of the $(\alpha, 3n)$ reaction on the 187 isotope affords a ready explanation of the shape of the yield curve. Further evidence was obtained from experiment with enriched rhenium isotopes. In Table II, it is seen that a very much greater yield of this activity was obtained from "Re 187," which was subjected under the same

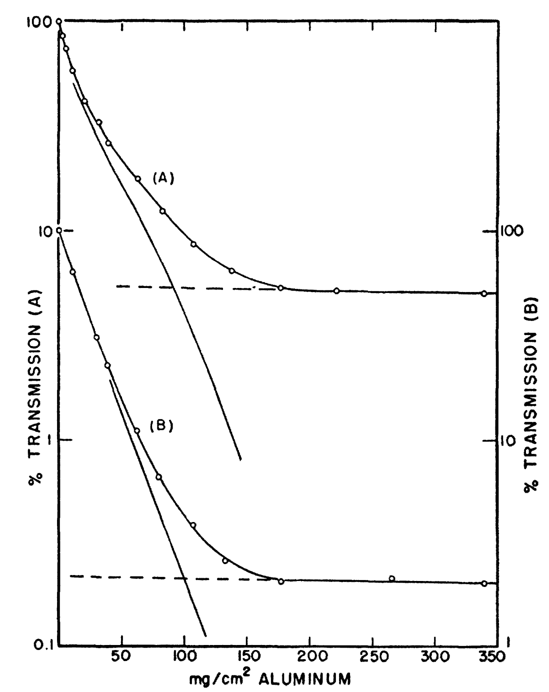


FIG. 8. Aluminum absorption curves for the 9.5-min. Os (A), and 6-hr. Os (B).

[7] Cork, Shreffler, and Fowler, Phys. Rev. **74**, 1657 (1948).

TABLE III. Cross sections in barns for $\alpha$-particle reactions on enriched Re.

| Sample | $\alpha$-energy (Mev) | 11.8-hr. $Ir^{187}$ | 41.5-hr. $Ir^{188}$ | 3.2-hr. $Ir^{190}$ | 12.6-day $Ir^{190}$ |
|---|---|---|---|---|---|
| "Re 187" | 22 | 0.009 | 0.13 | 0.01 | 0.24 |
| "Re 187" | 32 | — | 0.81 | 0.006 | 0.15 |
| "Re 185" | 32 | 1.2 | 0.21 | — | 0.022 |

experimental condition as "Re 185" (both being kept side by side at the center of the 32-Mev $\alpha$-beam). Since an $(\alpha, 3n)$ reaction should predominate over $(\alpha, n)$ at 32 Mev, the above assignment is confirmed.

The allocation of the 11.8-hr. activity to $Ir^{187}$ was strongly suggested by the joint bombardment of the enriched menium isotopes. With 32 Mev $\alpha$'s the "Re 185," which has been enriched to 85.38 percent $Re^{185}$ (Table I), gave a corresponding ratio of yield of the 11.8-hr. Ir activity (84.4 percent), and none of this activity was obtained from the "Re 187" (98.22 percent $Re^{187}$) target. Additional support was obtained from the 19-Mev deuteron bombardment on osmium; wherein $(d, n)$, $(d, 2n)$, and $(d, 3n)$ all were possible reactions. The relative yield of the 11.8-hr. Ir was about half as much as that of the 41.5-hr. Ir, which agreed with the ratio of the sum of the relative abundances of $Os^{186}$ 1.59 percent+$Os^{187}$ 1.64 percent+$Os^{188}$ 13.3 percent (total 16.53 percent available for $Ir^{187}$) and that of $Os^{187}$ 1.64 percent+$Os^{188}$ 13.3 percent+$Os^{189}$ 16.1 percent (31.04 percent available for $Ir^{188}$).

The 12.6-day period has been reported (as 10.7 day) and assigned to $Ir^{190}$ by Goodman and Pool.[2] The present work substantiates their conclusion. The assignment of the 3.2-hr. positron emitter as an isomer of $Ir^{190}$ rather than to $Ir^{188}$ was supported by the ratio of yield both from natural and enriched rhenium targets. The yield of the 3.2-hr. activity kept reasonable pace with that of the 12.6-day, but it was quite different from that of the 41.5-hr. period.

The cross sections for the production of the radioactive isotopes are given in Table III. In spite of the uncertainties involved in the absolute cross section calculations, the reliability of their relative values is worthy of mention. From Table I we see that the enriched "Re 187" sample contains 98.22 percent $Re^{187}$ isotope and the "Re 185" contains 14.62 percent $Re^{187}$. The rate of formation of the 12.6-day activity from the two enriched rhenium samples, $\sigma(Re^{187})/\sigma(Re^{185})=0.15/0.022=6.8$, corresponds very well to the ratio of the $Re^{187}$ percentage compositions, $98.22/14.62=6.7$. Meanwhile by considering the relative cross sections of the production of the 3.2-hr. and 12.6-day activities from 22-Mev $\alpha$- and 32-Mev $\alpha$-bombardments, the ratio of the two members of $Ir^{190}$ isomer may be estimated as about 1:20.

We should expect $Ir^{186}$ and $Ir^{189}$ to appear in this experiment as results of $(\alpha, 2n)$ and $(\alpha, 3n)$ reactions on Re. But since no other activity was apparent from 21-Mev $\alpha$- up to 38-Mev $\alpha$-bombardments (from 1 $\mu$ah to 15 $\mu$ah), we must presume that their half-lives are long or fairly short. In the latter case any radioactivity with a half-life less than 5 min. would have been difficult to observe, since there was necessarily a delay of $\frac{3}{4}$ hr. to one hr. between the end of bombardment and the first count. Whether the above-mentioned weak period of more than 100 days can be assigned to either of these, will require further study, but it could feasibly be $Ir^{189}$, which can be expected to have a comparatively long half-life.

The relative yields of osmium activities, found growing in the iridium fraction, and also found in the osmium fraction from Re+$\alpha$-bombardment, were very small. They were probably formed as daughters of the Ir activities. The initial samples were all very weak, one could only relate the 9.5-min. Os to the 3.2-hr. Ir with certainty. The results of milking experiments suggested, in addition, a possible relationship between the 6-hr. Os and the 12.6-day Ir, and between the 35-hr. Os and the 11.8-hr. Ir. Since osmium isotopes of masses 186 through 190 exist in nature, any radioactivity due to them must be associated with the existence of excited states of the stable isotopes.

The author takes pleasure in expressing his gratitude to Professors G. T. Seaborg and W. M. Latimer for the opportunity of working at the Radiation Laboratory and the Department of Chemistry of the University of California. Special acknowledgment is made to Professor G. T. Seaborg who suggested the problem and offered many helpful suggestions and to Dr. E. K. Hyde, Dr. B. Jones, Dr. G. Wilkinson and other members of the laboratory for valuable discussions and assistance. He is also very grateful to Mr. T. M. Putnam, Jr., Mr. G. B. Rossi, Mr. J. T. Vale, and the crew members of the 60-inch and the 184-inch cyclotrons for their cooperation and assistance in making bombardments.