Radiations from Os^{185}, Os^{191}, and Os^{193}*

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The radiations from Os^{185} (97 days), Os^{191} (32 hr.) and Os^{193} (15 days) have been investigated with the help of a magnetic lens spectrometer. Os^{185} decays by orbital electron capture accompanied by two gamma-rays of energy 0.648 and 0.878 Mev. The number of gamma-ray quanta of 0.648 Mev is six times that of 0.878 Mev. Os^{191} decays by the emission of beta-rays of maximum energy 1.10 Mev and does not appear to be accompanied by any gamma-rays. Os^{193} decays by beta-particle emission accompanied by two gamma-rays of energy 0.128 and 0.041 Mev. The beta-ray spectrum is obscured by internal conversion and Auger lines. The end point is approximately 0.135 Mev.

I. INTRODUCTION

WHEN osmium is bombarded with slow neutrons, three activities result with respective half-lives of approximately 32 hr., 15 days, and 97 days. The 15-day activity has been associated with Os^{193}. Early measurements[1] indicated that the half-life was 17 days, but by correcting for the presence of the 97-day activity, Katzin and Pobereskin[2] have shown it to be nearer 15 days. They report the decay to take place by emission of a beta-ray of energy not more than 0.165 Mev, followed by a highly converted 0.13-Mev gamma-ray and abundant x-rays. More recently, the spectrometer measurements of Saxon[3] have revealed a beta-ray end point of 0.142 Mev and two gamma-rays, one of 0.127 Mev and the other 0.039 Mev.

The 97-day activity is attributed to Os^{185} and was first observed by Goodman and Pool,[4] who produced it by a deuteron bombardment of rhenium. Katzin and Pobereskin[2] have also produced the activity with slow neutrons, and their absorption measurements indicated the presence of a 0.75-Mev gamma-ray and K and L x-rays. They found a relatively high ratio of soft quantum to hard quantum counts, and concluded that Os^{185} must decay predominantly by orbital electron capture.

Seaborg and Friedlander[1] assigned the 32-hr. activity to Os^{191} and reported that the radiation consists of a 1.5-Mev beta-ray and at least one gamma-ray. Goodman and Pool[4] have produced this activity by the action of deuterons on osmium and, using absorption methods, found a beta-ray end point of 0.95 Mev and a 1.17-Mev gamma-ray. Later Mandeville, Scherb, and Keighton,[5] using an osmium source which had been exposed to neutrons in a pile for one-half hour, measured

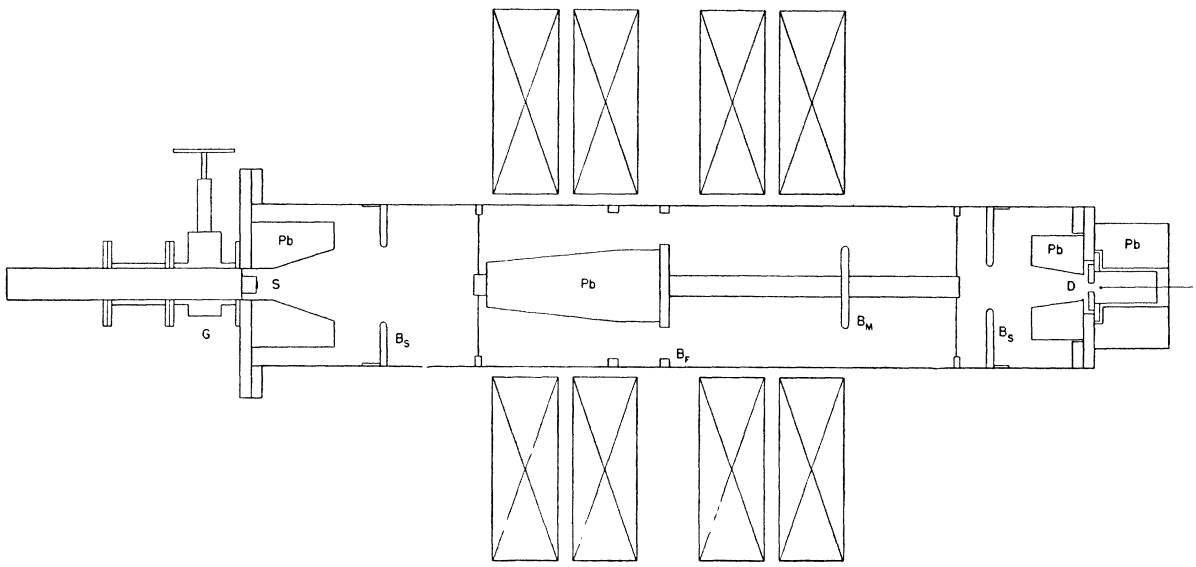

FIG. 1. Schematic diagram of the magnetic lens.

* This research was assisted by the joint program of the ONR and AEC.
[1] G. T. Seaborg and G. Friedlander, Phys. Rev. **59**, 400 (1941).
[2] L. I. Katzin and M. Pobereskin, Phys. Rev. **74**, 264 (1948).
[3] D. Saxon, Phys. Rev. **74**, 1264 (1948).
[4] L. J. Goodman and M. L. Pool, Phys. Rev. **71**, 288 (1947).
[5] Mandeville, Scherb, and Keighton, Phys. Rev. **71**, 288 (1947).

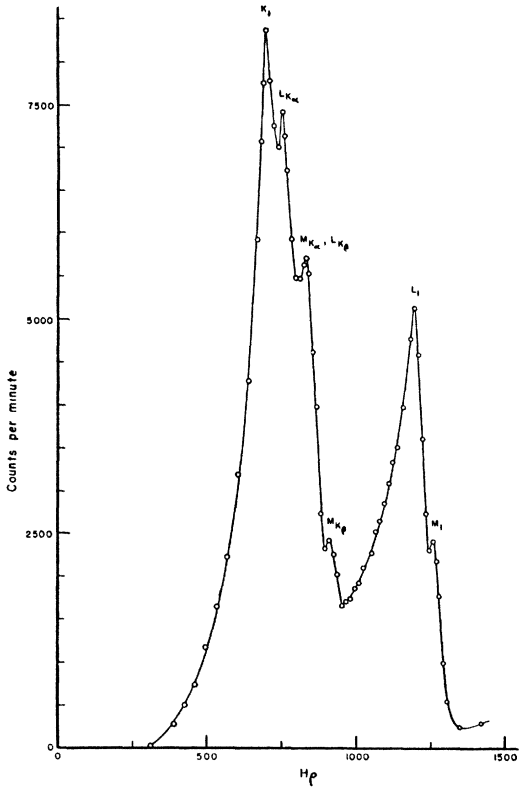

FIG. 2. Photo-electrons ejected from lead by gamma- and x-rays of Os^{193} and Os^{185}. (K_1—0.128-Mev Os^{193}); ($L\kappa_\alpha$ and $L\kappa_\beta$—x-rays of Ir^{193} and Re^{185}).

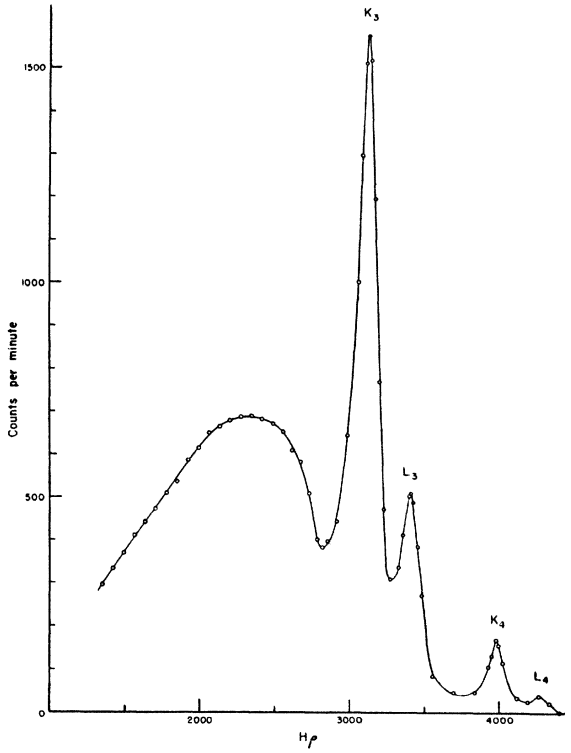

FIG. 3. Secondary electrons ejected from lead by gamma-rays of Os^{185}. (K_3—0.648 Mev); (K_4—0.878 Mev).

the beta-ray end point by absorption techniques and found a value of 1.15 Mev. In addition they found gamma-rays of energy 0.22 and 1.58 Mev. A small number of beta-gamma- and gamma-gamma-coincidences were observed.

In an effort to clarify some of the above-mentioned discrepancies, the radiations from the three osmium activities have been investigated with the aid of a magnetic lens spectrometer. No previous investigators have made a spectral analysis of both the beta- and gamma-radiations from these isotopes with an instrument of comparable resolving power.

II. APPARATUS

The magnetic lens spectrometer used in this work is of conventional design, similar to the instrument described by Deutsch, Elliott, and Evans.[6] The magnetic field used for focusing electrons is produced by four water-cooled coils which can be moved in pairs. Each coil measures $3\frac{5}{32}$ in. in thickness, $8\frac{1}{2}$ in. I.D., 28 in. O.D., and is wound with 1356 turns of 0.136 in. sq. copper wire covered with glass fiber insulation. Inner or outer coil sections may be used separately. In this experiment the coil pairs were $3\frac{1}{8}$ in. apart, placed symmetrically with respect to the center of the system, and all coil sections were used.

The vacuum chamber (Fig. 1) is a seamless brass tube 8 in. in diameter and 39 in. long containing suitable baffles and shielding. The fixed ring, B_F, and the movable disk, B_M, define the annular opening of the spectrometer. The size of the annulus through which the electrons are accepted is adjusted by moving the inner defining disk. This adjustment is made by means of a rod which passes through a Wilson seal at the end of the tube. Antiscattering baffles, B_S, and the lead shielding reduce the scattered and direct background radiation. The source ring, S, is placed in a Lucite holder mounted on the end of a brass tube which is passed into position through a gate valve and Wilson seal. The counter and its lead shield are fastened to the cover plate at the other end of the chamber and connections are made to a ballast tank so the counter can be evacuated and filled in position. This permits the use of thin zapon and Formvar films for counter windows.

The earth's magnetic field is neutralized in the region of the spectrometer chamber by a pair of rectangular coils, placed above and below the vacuum chamber with their axes parallel to the earth's field.

Since the instrument contains no iron, the focusing field is proportional to the current. The instrument has been calibrated by measuring the annihilation radiation

[6] Deutsch, Elliott, and Evans, Rev. Sci. Inst. **15**, 178 (1944).

from Cu^{64} and the 0.4112-Mev gamma-ray of Au^{198}. The spectrometer can focus 8.5-Mev electrons with present current sources and it is intended that this instrument eventually be used to study prompt and short-lived gamma-radiation.

With the present coil location, and using sources and counter windows of 7-mm diameter, the lens gives two percent resolution at high resolution adjustment on the basis of the half-width of internal conversion lines. At low resolution setting it gives three percent.

The osmium sources used in the experiment were obtained from the Oak Ridge pile of the U. S. AEC. The active metallic osmium powder was purified chemically and precipitated as Os_2S_3, in which form it was used in this work.

III. GAMMA-RAY MEASUREMENTS

To investigate the gamma-rays of osmium, the osmium sulfide, exhibiting activities of all three periods, was placed in a cylindrical copper capsule 9 mm O.D., with walls and end just thick enough to stop all beta-rays. The flat end of the capsule was covered with a lead sheet of 16-mg/cm^2 surface density, which served as a radiator of secondary electrons. The distribution of photo-electrons and Compton electrons ejected from this thin lead radiator by the osmium gamma-radiation was examined in the lens a few hours after the source was received from Oak Ridge. The secondary electron spectrum obtained is shown in two parts, the low energy spectrum in Fig. 2 and the higher energy spectrum in Fig. 3. Although subsequent measurement of the beta-ray spectrum revealed a prominent beta-ray group which decayed with the 32-hr. half-life of Os^{191}, no portion of the gamma-spectrum was found to be associated with this period.

Referring to Fig. 2, the K, L, and M peaks at 695, 1193, and 1264 gauss-cm correspond to a gamma-ray of energy 128 kev. This line was observed to decay with a half-life of the order of 15 days and therefore is associated with the isotope Os^{193}. The peaks at 753, 831, and 916 gauss-cm were found to decay at a rate intermediate between the half-lives of Os^{193} and Os^{185}. This fact, plus consideration of the energy values, identifies these peaks as due to photoelectrons ejected from the L and M shells of the lead radiator by the K_α and K_β x-rays from the decay products Ir^{193} and Re^{185}. For example, by assuming that the peak at 753 gauss-cm is due to photo-electrons ejected from the L shell of lead, the corresponding photon energy is found to be 63.6 kev. Since the K_α x-rays of iridium and rhenium have respective energies of 64.1 and 60.6 kev,[7] it would appear that the peak in question is due mainly to the x-rays from iridium, as one would expect from the initial ratio of activities of the Os^{193} and Os^{185}. It was observed that as this ratio changed with time, the three peaks associated with the x-rays shifted nearer to the positions one would expect them to occupy if the x-rays were due entirely to rhenium.

In Fig. 2, the prominent K and L photo-electron peaks at 3128 and 3408 gauss-cm correspond to a

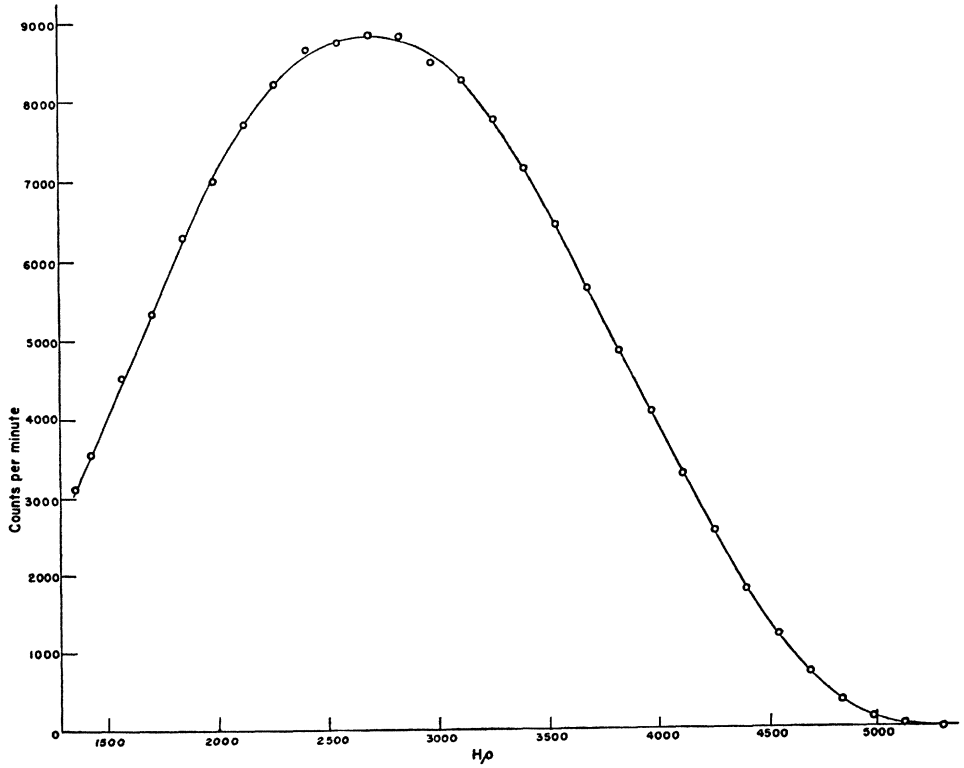

FIG. 4. Beta-ray spectrum of Os^{191}.

[7] A. H. Compton and S. K. Allison, *X-Rays in Theory and Experiment* (D. Van Nostrand Company, Inc., New York, 1935).

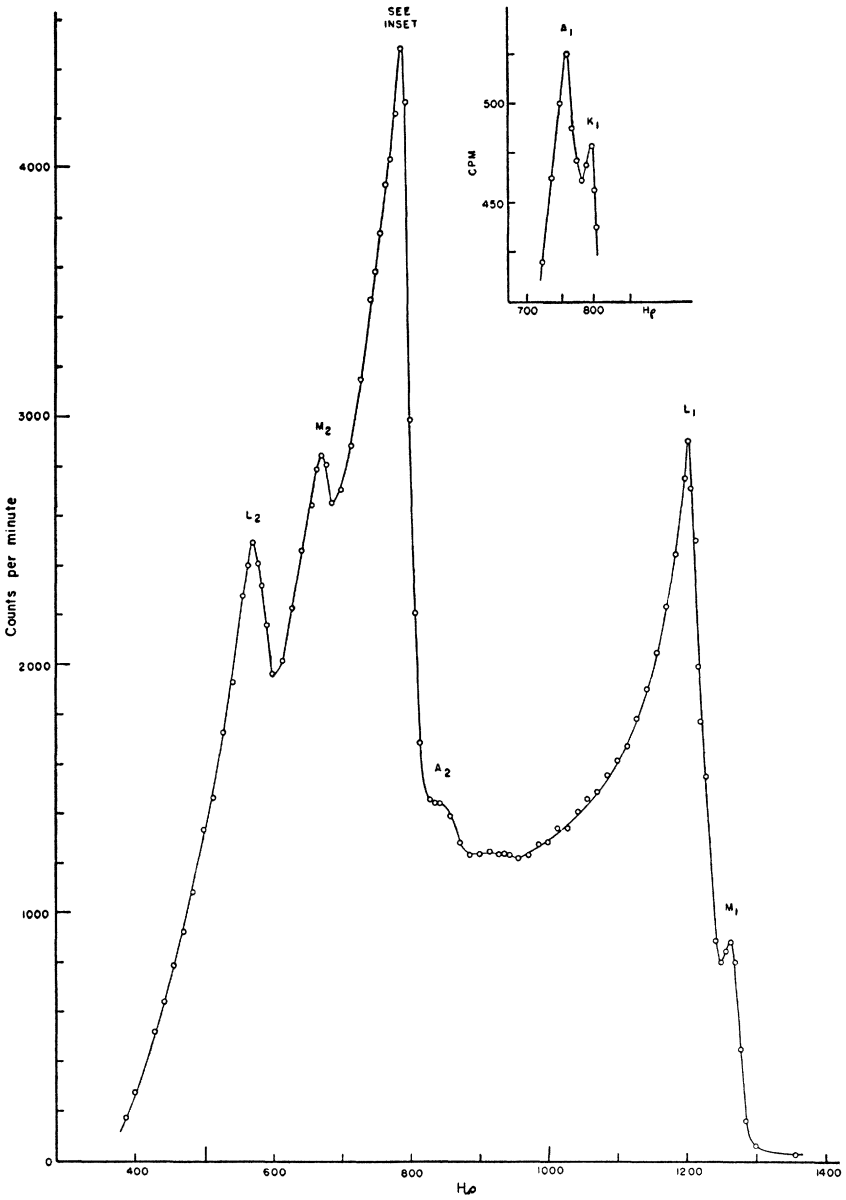

FIG. 5. Low energy beta-ray spectrum of Os^{193} and Os^{185}. (K_1—0.128-Mev Os^{193}); (L_2—0.041-Mev Os^{193}); (A_1 and A_2—Auger lines from Ir^{193} and Re^{185}).

gamma-ray of 648-kev energy, and the two smaller peaks farther out on the curve correspond to the K and L peaks of a gamma-ray of 878-kev energy. Intensity measurements taken over a period of months indicate that the half-life of both lines is in the neighborhood of 95 days. Consequently, these two gamma-rays undoubtedly arise from the isotope Os^{185}. The areas under the 648- and 878-kev lines have been integrated graphically (on an $N/H\rho$ plot) and their ratio taken after properly correcting for the variation of the photoelectric absorption coefficient as a function of the energy by use of Gray's[8] empirical data. This gives a value of 6:1 for the ratio of the number of quanta of 648-kev energy to the number of quanta of 878-kev energy.

[8] L. H. Gray, Proc. Camb. Phil. Soc. **27**, 103 (1931).

IV. BETA-RAY MEASUREMENTS

In order to have a beta-ray source of sufficient activity that the spectrum could be studied over a period of months so that the various activities could be separated, it was necessary to use a source of about 10-mg/cm² surface density. The source material was mounted on a paper backing of surface density 0.67 mg/cm² and covered with a thin layer of zapon. An examination of the beta-ray spectrum approximately half a day after the source was received from Oak Ridge revealed the presence of a high energy beta-group and a relatively much stronger group of peaks below 1350 $H\rho$. Measurement of the decay of the higher energy group gave a half-life of about 32 hr., and consequently this group was identified as the hard beta-ray of Os^{191}

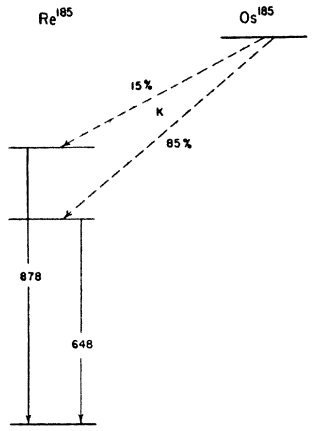

FIG. 6. Proposed disintegration scheme for Os^{185}.

found by previous investigators. Superimposed on this beta-group were small peaks identified by their energies and rate of decay to be due to internal conversion electrons from the 648- and 878-kev lines of Os^{185}. Thus to obtain the true shape of the beta-spectrum of Os^{191}, the contribution from the Os^{185} was measured some three weeks after the initial run, corrected for decay, and subtracted from the original composite spectrum. The result is shown in Fig. 4. The curve does not extend below 1350 gauss-cm due to interference from the low energy group. A Fermi plot has been made of this spectrum, using the approximation for the Coulomb correction factor, $F(Z, E)$, given by Bethe and Bacher.[9] The end-point energy was found to be 1.10 Mev. The ft value was calculated to be 2.1×10^7 and thus the transition would be expected to be either first or second forbidden.

The prominent low energy group mentioned above was found to be due mainly to the 15-day Os^{193}. The curve of Fig. 5 shows the appearance of this group after a three-week interval had been allowed to elapse in order to eliminate interference from the 32-hr. activity. After the elapse of several additional months, the peak at 782 gauss-cm was found to be complex, as shown in the inset of Fig. 5. By assuming that the peaks at 792, 1203, and 1264 gauss-cm are produced by internal conversion in the K, L, and M shells of Ir^{193}, one obtains a value of 128 kev for the energy of the gamma-ray, which agrees with the value obtained from the gamma-spectrum. The peaks at 570 and 670 gauss-cm, which were also found to decay with the 15-day period, correspond to electron energies of 28 and 38 kev. Since the L and M binding energies of iridium also differ by 10 kev, it is concluded that these peaks are due to internal conversion electrons produced by a 41-kev gamma-ray from Os^{193}. The peaks at 760 and 835 gauss-cm are identified as composite Auger electron lines resulting from the internal conversion process in Ir^{193} and the K-capture process of Os^{185}.

It is readily seen, by further examination of the curve of Fig. 5, that in addition to the peaks discussed above, there is some sort of underlying electron distribution. This distribution can reasonably be assumed to be the beta-ray spectrum of Os^{193}. However, this beta-ray group is so completely obscured by the internal conversion electrons that little can be said with certainty about its maximum energy, its complexity, or its intensity. It is possible, but not definite, that the flat region of the curve in the vicinity of 925 gauss-cm is a portion of the beta-ray spectrum. At least this portion of the curve establishes a maximum height for the beta-spectrum. Also it is evident that the beta-ray spectrum does not extend beyond about 1300 gauss-cm (135 kev).

V. DISCUSSION

The results which have been obtained on Os^{185}, Os^{191}, and Os^{193} are discussed below.

(a) Os^{191}

Os^{191}, whose half-life is 32 hr., appears to decay entirely by beta-ray emission unaccompanied by gamma-rays. The maximum energy of the beta-rays determined as a result of the present measurements is 1.10 Mev, and the comparative half-life is 2.1×10^7 sec.

(b) Os^{185}

Os^{185} appears to decay entirely by orbital electron capture. After all other osmium activities had been allowed to die out, the source was investigated in a 180°-type beta-ray spectrograph. No positrons were found in this investigation. As has been mentioned above, there are two gamma-rays associated with the decay of Os^{185} of energies 0.878 and 0.648 Mev. No gamma-ray corresponding to the difference of these two energies was found. The number of quanta of 0.648 Mev is approximately six times the number of quanta of 0.878 Mev, so there is no possibility that these two gamma-rays can be in cascade. It would appear, therefore, that in the process of orbital electron capture, two separate levels of Re^{185} are excited, one at 0.648 Mev and one at 0.878 Mev. In order to be sure that there are no gamma-rays in cascade, Mr. W. H. Cuffey of this laboratory investigated a source of Os^{185} in a coincidence counting apparatus and found no gamma-gamma-coincidences. The disintegration scheme of Os^{185} is shown in Fig. 6.

(c) Os^{193}

The measurement of the spectrum of Os^{193} is complicated by the presence of x-rays which are of the same order of magnitude in energy as that of the lower energy gamma-ray. In addition, the measurement of the beta-ray spectrum is complicated by the presence of strong internal conversion lines and Auger lines. The end point of the beta-ray spectrum is certainly not greater than 135 ± 5 kev and it is impossible to tell whether the spectrum is simple or complex. There are two gamma-ray lines of energies 128 and 41 kev. Owing to the presence of Auger electrons it is impossible to say much about the relative intensities of these lines. Both lines are highly internally converted.

The authors are indebted to Miss Elma Lanterman for making the chemical separations and to Mr. W. H. Cuffey for making the coincidence measurements.

[9] H. A. Bethe and R. F. Bacher, Rev. Mod. Phys. 8, 194 (1936).