Internally Converted Radiation from Europium, Hafnium, and Osmium

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By use of semicircular focusing, magnetic spectrometers, together with absorption methods, the gamma-radiations emitted by europium 154, hafnium 181, and osmium 193 are evaluated. These energies are as follows: for europium (154)—122.4, 342.8, 407.8, and 1230 kev; for hafnium (181)—132.5, 345.5, 478.7, and 600 kev (by absorption); and for osmium (193)—129.1 kev. Two cases are shown where photoelectrons and conversion electrons from the same gamma-ray are of comparable intensity. The ability of the radioactive method in chemical analysis to show traces of impurities is demonstrated.

WITH the apparatus described in previous reports,[1] data have been obtained on the radioactivity of the following isotopes—europium 154, hafnium 181, and osmium 193. The samples studied were obtained through the Atomic Energy Commission by irradiation in the Oak Ridge pile.

EUROPIUM 154

Previous studies[2] had shown the existence of a radioactive isotope of europium of half-life about 6 years, whose beta-spectrum had an upper limit of 0.9 Mev. On exposing a supposedly very pure sample of europium to the neutron activity of the pile, a very intense radioactivity was induced by the (n, γ) reaction. Subsequent observations showed the probable presence of an impurity of the related element, neodymium. The active sample was studied by observing the absorption of its radiation in lead, copper, and aluminum with a string electrometer and ionization chamber, and photographically in the magnetic spectrometers.

A typical photogram of the beta-spectrum is shown in Fig. 1. The three horizontal strips represent different exposure times with the same magnetic field. Several lines due to internal conversion are apparent. If the internal conversion follows after the emission of a beta-particle from the excited europium, whose atomic number is 63, then the *K-L-M* differences present should be those of the next heavier element, namely, gadolinium. A collection of all measurable lines expressed in terms of energy is presented in Table I, and shown graphically in Fig. 2. The interpretation of each line is presented in column 2, and the final gamma-energies in the last column.

Two observations of special interest can be made in addition to that relating to the gamma-lines for this element. It is apparent that the gamma line of energy 0.122 Mev is satisfied both by a *K-L-M* combination characteristic of gadolinium (64), and europium (63). It must then be that in this case the ejection of photoelectrons in the parent europium by the uncon-

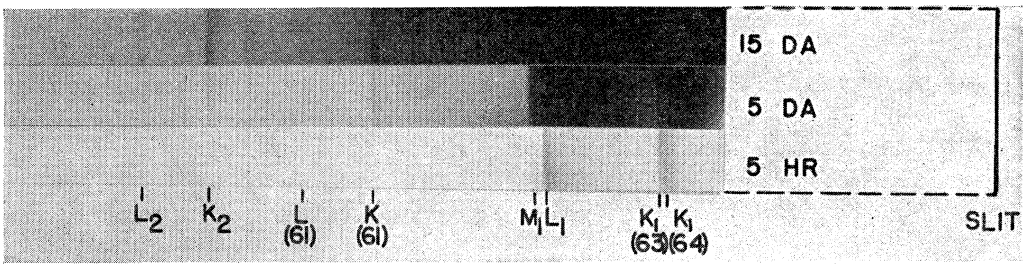


FIG. 1. The conversion spectrum of europium 154, for exposure times of 5 hours, 5 days, and 15 days.

[1] J. M. Cork, Phys. Rev. 72, 581 (1947).
[2] K. Fajans and A. Voigt, Phys. Rev. 60, 533 (1941).

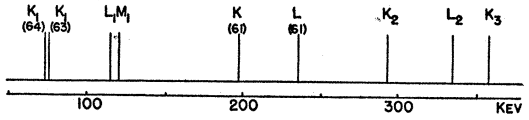


FIG. 2. The energy distribution of the complete europium 154 spectrum.

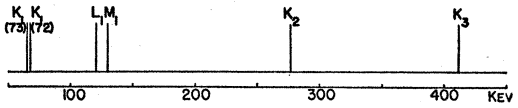


FIG. 4. The energy distribution of conversion lines for hafnium 181.

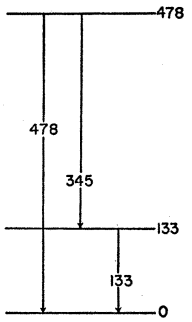


FIG. 5. Energy levels in tantalum 181 after the emission of a beta-particle from hafnium 181.

verted gamma-radiation happens to be of the same order of magnitude as the production of electrons by internal conversion in the relatively few decaying gadolinium nuclei.

It can also be observed that one group of lines have energy separations characteristic of the *K-L-M* differences for the element of atomic number 61. They satisfy a gamma-energy of 244 kev. This indicates that neodymium (60) might have been present as an impurity in the europium. However, no long half-lived activities have previously been reported in neodymium, and over the few months of the present observation the intensity of these lines has not diminished by any large amount. From the remaining lines, it can be concluded that in europium there are three strong gamma-rays of energy, 122.4, 342.8, and 407.8 kev. Absorption measurements in copper, iron, and lead indicate the presence of a higher energy gamma-ray at 1.23 Mev.

The upper limit of the beta-spectrum was observed by its absorption in aluminum (0.132 cm), and in the magnetic spectrometer to be about 0.93 Mev. A more complete study of the form of the beta-distribution is being made. No simple scheme is apparent that would reduce the number of levels required to satisfy the observed gamma-energies.

HAFNIUM

When hafnium is subjected to neutron radiation a radioactive isotope of mass 181 can be produced by the (n, γ) reaction. An activity of half-life 55 days had been reported by Hevesy,[3] but the radiation emitted was not recorded. A sample of pure hafnium oxide was strongly activated by irradiation in the pile. When placed in the magnetic spectrometer many conversion lines were obtained.

Table II shows collectively the energies of the observed lines together with their interpretation and the consequent energies of the gamma-rays. It is again evident that for the gamma-ray of energy 132.5 kev the photoelectrons are about equal in number to the conversion electrons so that two *K*-lines are present, one being for hafnium, and the other for tantalum. These are shown in the low energy photogram reproduced in Fig. 3. A summary of all observed lines with their corresponding energies is shown in Fig. 4. Evidence for the existence of an additional

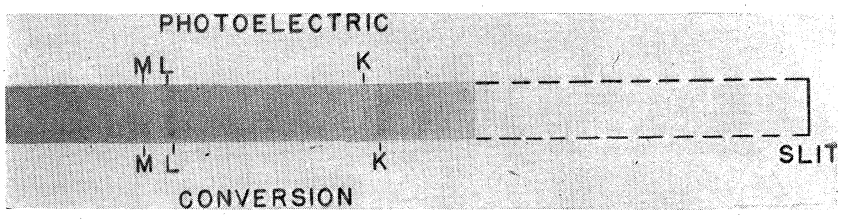


FIG. 3. Low energy portion of the beta-spectrum of hafnium 181, showing both photoelectric and internal conversion electrons.

[3] G. Hevesy and G. Levi, Nature **137**, 185 (1936).

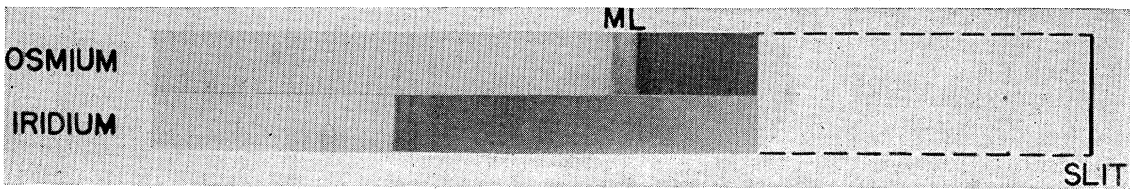


FIG. 6. Photogram showing the presence of iridium in the osmium specimen.

TABLE I. Beta-spectrum of europium.

Observed energy	Identification	Gamma-energy
71.8 kev	$K_1(64)$	122.1 kev
73.8	$K_1(63)$	122.4
114.4	L_1	122.8
120.0	M_1	121.9
197.0	$K(61)$	244.4
235.7	$L(61)$	243.6
292.4	K_2	342.7
334.5	L_2	342.9
357.5	K_3	407.8

TABLE II. Beta-spectrum of hafnium.

Observed energy	Identification	Gamma-energy
65.1 kev	$K_1(73)$	132.5 kev
67.0	$K_1(72)$	132.4
120.6	L_1	132.3
129.9	M_1	132.6
276.8	K_2	344.2
411.3	K_3	478.7

gamma-ray at an energy of about 0.60 Mev is obtained from measurements of the absorption in copper and aluminum.

The three observed gamma-rays offer the relationship that the sum of two of them is very close in value to that of the third, so that the level scheme of Fig. 5 appears valid, and must in part represent the possible levels in excited tantalum 181.

OSMIUM

A radioactive isotope of osmium of half-life 17 days had been reported.[4] This was produced by neutron bombardment and assigned to mass 193 being derived from the abundant natural isotope of mass 192 by the (n, γ) reaction. Powdered, metallic osmium was irradiated in the pile and as a result yielded a strong radioactivity.

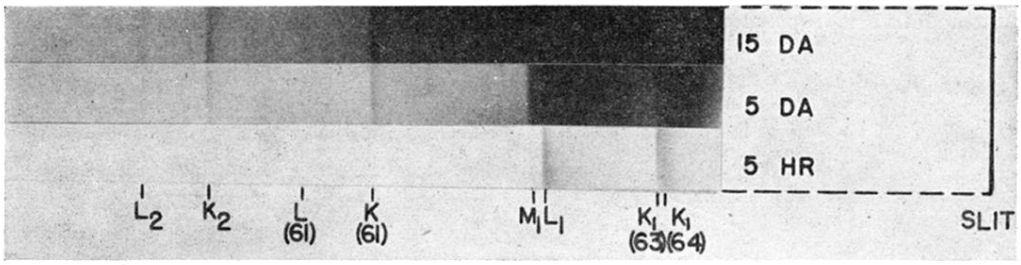
When placed in the spectrometer, many lines were recorded in the spectrum photographically. The pattern of certain of the lines obtained seemed very familiar, and on analysis it was found to agree with the recorded[1] values for iridium. Certain additional strong lines were present.

In Fig. 6 the lines obtained with osmium are shown directly above the corresponding strong lines for iridium. Since the osmium was supposed to be chemically pure, it became of interest to know to what extent the iridium was present in order to evaluate this radioactive method as a tool for chemical analysis in certain cases. Dr. R. A. Wolfe made a rather exhaustive spectroscopic analysis of the osmium, and concluded that there was much less than one percent of iridium present. In spite of this small quantity, it is apparent that the lines are quite strong. Thus, impurities with extraordinary large capture cross sections may be revealed by the radioactive method when present in very minute quantities.

The strong lines attributed to osmium form an L-M combination characteristic of iridium as expected after beta-emission. They have energies of 126.2 and 115.6 kev, which yield a single gamma-ray of 129.1 kev.

This investigation was made possible by the support of the Office of Naval Research.

[4] G. T. Seaborg and G. Friedlander, Phys. Rev. 59, 400 (1941).



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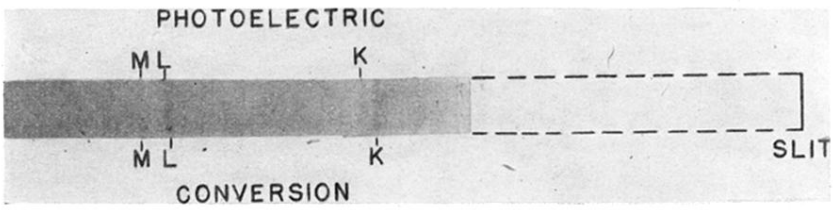

FIG. 3. Low energy portion of the beta-spectrum of hafnium 181, showing both photoelectric and internal conversion electrons.

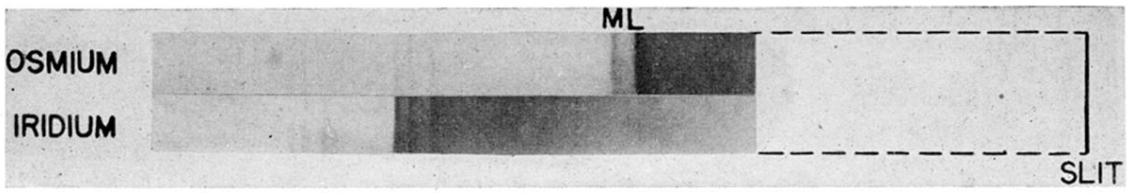

FIG. 6. Photogram showing the presence of iridium in the osmium specimen.