Gamma-Radiation from Tantalum, Iridium, and Gold

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By using a photographic method in connection with semi-circular focusing magnetic spectrometers, the beta-spectra due to internal conversion have been evaluated for gold 198, iridium 194, and tantalum 182. For gold a simple spectrum of 3 lines with differences the same as between the *K-L-M* levels of mercury indicate a single gamma-ray of energy 0.408 Mev following beta-emission.

In iridium, a complicated spectrum of more than 26 lines is observed which may be identified from the *K-L-M* differences in platinum as due to 12 gamma-rays. These gamma-energies appear to fit well with a level scheme of six terms.

Tantalum yields a spectrum of about 34 lines from which about 16 gamma-rays may be derived by applying the *K-L-M* differences for tungsten. These gamma-energies fit satisfactorily on a level scheme of 9 terms.

IN preliminary reports[1] it has been shown that both tantalum and iridium yield beta-spectra with a multitude of superimposed lines due to internal conversion. In each of these cases it is now possible to associate the lines in K, L, and M groups and evaluate the discrete gamma-energies. It is then possible to construct energy-level schemes of relatively few terms from which the many gamma-rays may be derived by various transitions.

APPARATUS

This investigation makes use of the photographic method in magnetic spectrometers of the semi-circular focusing type. Three different instruments are in operation, one of which is excited by a stabilized electric current while the other two are of the permanent magnet type. In the latter, the "Alnico" component of the magnetic circuit is excited to any desired state by sending a momentary current through surrounding exciting coils. Figure 1 shows schematically the arrangement of the magnetic circuit.

The magnetic field is measured by an absolute method in which a rotor with commutator is driven at constant speed by a synchronous motor. The direct voltage output of the d.c. generator so formed is applied to a Leeds and Northrop K-2 potentiometer. Several spinners of this sort have been constructed with sensitivities varying from 10 to 100 microvolts per gauss. It is thus possible, with the high sensitivity of the potentiometer to measure the field very precisely provided the rotor can be driven at a constant speed.

Although some power companies do remarkably well at controlling the frequency, so that the net gain or loss in cycles over the interval of a week is negligible, sizable short-period fluctuations are impossible to avoid. To overcome this difficulty a thyrotron oscillator was constructed to drive the synchronous motors. The frequency of the output of this device is satisfactorily stable.

The radioactive samples were obtained through the Atomic Energy Commission from Oak Ridge, being produced in the pile by the (n, γ) reaction. Each specimen was mounted on a thread-like support on an aluminum frame. No metal was close to the source. The mass of the sample and support was made as small as possible, com-

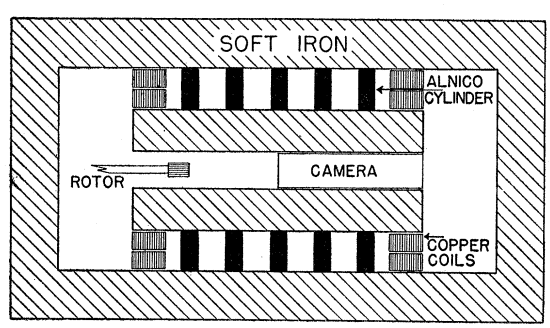

FIG. 1. Sketch of section of permanent magnet for spectrometer.

[1] J. M. Cork, R. G. Shreffler, A. D. Weaver, and F. B. Shull, Phys. Rev. **71**, 467 (1947).

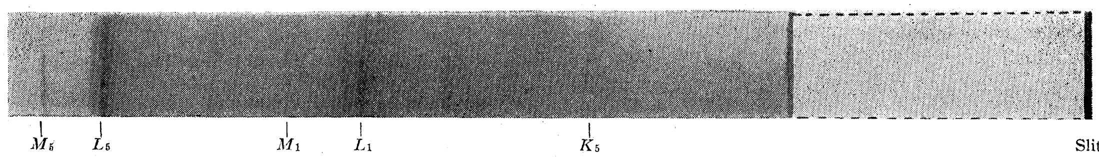

FIG. 2. Low energy portion of tantalum beta-spectrum.

patible with giving a satisfactory exposure in a reasonable time. In practice, a technique was developed in which a thin organic strip about 0.3 mm wide was uniformly coated with the sample on one side, so that the mass per cm was of the order of 0.10 mg. This geometry minimizes the broadening of the spectral lines by scattering or partial absorption in the source, and good exposures were obtained in from one to six days.

TABLE I. Gold beta-spectrum.

Observed energy	Identification	Gamma-energy
326 kev	K	406.5 kev
394 kev	L	408.4 kev
405 kev	M	408.4 kev

RESULTS

Each isotope was allowed to give several spectrograms under varied conditions. A typical plate showing a portion of the tantalum spectrum is reproduced in Fig. 2. It is apparent from the sharpness of the lines that partial energy loss within the sample is negligible. Iridium was used in the finely powdered metallic state and was not so favorable in this respect. Because of a lack of focusing in the vertical direction, the intensity of a line falls off with increased distance from the source so that a longer time is required for outlying lines.

Estimates of relative intensity can be made by covering half of the plate with an adjustable shutter during any fixed portion of the exposure.

Gold

The isotope of gold of mass 198 has been known,[2] since the early survey of Fermi, to be radioactive with a half-life of 2.7 days. It has been reported as emitting beta-radiation of maximum energy 0.78 Mev and gamma-rays of energy 0.28, 0.44, and 2.5 Mev. Only one of these gamma-rays appears to be strongly converted, and the spectrum in this case consists of only three lines. The differences in the energies of these lines agrees well with the differences between the K, L, and M levels in mercury. This indicates that the gamma-emission follows the loss of the beta-particle from the excited gold isotope. The observed average energies are presented in Table I. These values indicate for the

TABLE II. Beta-spectrum of iridium.

Observed energy	Identi-fication	Gamma-energy	Observed energy	Identi-fication	Gamma-energy
129.8	?	— kev	376	K_{13}	454.1 kev
162.5	?	—	387.3	K_7 or	465.4
				L_5	401.2
190.9	K_1	269.0	398.8	K_8	476.9
214.9	K_2	293.0	439.5	L_{13}	453.4
227.9	K_3	306.0	451.7	L_7	465.6
236.2	K_4	314.3	462.8	L_8 or	476.7
				M_7	466.1
254.5	L_1	268.4	507.5	K_9	585.6
280.5	L_2	294.4	524.0	K_{10}	602.1
292.5	L_3	306.4	531.0	K_{11}	609.1
301.5	L_4	315.4	572.8	L_9 or	586.7
				K_{12}	650.9
311.5	M_4	314.8	586.7	L_{10}	600.6
323.5	K_5	401.6(?)	597.0	L_{11}	610.9
330.3	K_6	408.0(?)	638.0	L_{12}	651.9

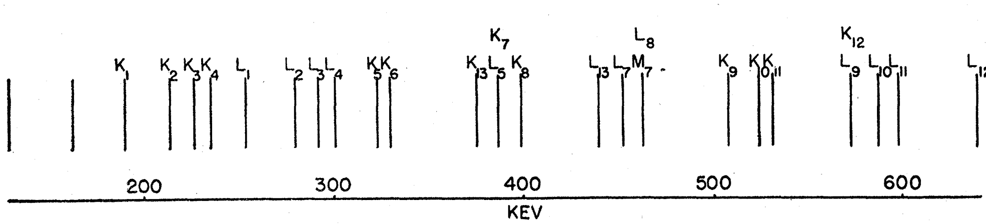

FIG. 3. The collected beta-spectrum of iridium on an energy scale.

[2] E. Amaldi, O. D'Agostino, E. Fermi, B. Pontecorvo, F. Rosetti, and E. Segrè, Proc. Roy. Soc. 149, 522 (1935).

energy of the gamma-ray an averaged value of 0.408 Mev.

Iridium

The isotope of iridium of mass 194 has previously been shown[3] to be radioactive with a half-life of 60 days. The beta-spectrum has not been studied but gamma-rays of energy 0.31, 0.47, and 0.60 Mev were reported. In the present investigation a sample of metallic iridium was activated, and because of the difficulty of getting it in solution the metal was pulverized in an agate mortar and applied to the specimen holder. When suitably exposed, many lines were obtained on the photographic plate. To cover completely the energy range, photographs were taken with several different magnetic fields.

The averaged values for the energies of the various lines obtained from the several plates are shown in Table II, and presented graphically in Fig. 3. By applying the known *K-L-M* differences for tungsten it becomes possible to detect certain groups among the lines, each group representing a single gamma-ray. From the 26 reasonably strong lines shown, 12 gamma-rays can be identified and are listed in Table III. In certain cases the interpretation of a line is not unique. Moreover, several additional lines are faintly apparent on the plates but because of low intensity are not included in the summary.

Having determined the gamma-energies, it becomes of interest to see if any relatively simple level scheme could be proposed, which would account for the numerous gamma-rays. The appearance of the lines in triplets of identical spacings offered encouragement in the search. It was soon evident that certain simple mathematical combinations could be formed. As a result, the scheme proposed in Fig. 4 seems reasonable. It is conceivable that some alternate plan may be equally good. With this scheme it is thus possible to account for 10 of the observed gamma-lines with 6 levels. In fact, almost every transition, except those at very low energies, that would be considered possible is actually observed, and the difference between the observed and expected values is less than 1 kev. However, many modifications of this scheme may ultimately be necessary when the weaker lines, not included here, are considered.

TABLE III. Summary of gamma-energies (averaged) for iridium.

Line	Energy	Line	Energy
1	269.0 kev	7	465.5 kev
2	293.7	8	476.8
3	306.2	9	586.2
4	314.8	10	601.4
5	401.4(?)	11	610.0
6	408.0(?)	12	651.4
		13	453.6(?)

Tantalum

The radioactive isotope of tantalum of mass 182 whose half-life is 97 days had been reported[4] to emit electrons of maximum energy 0.53 Mev. For the present investigation an oxide of the metal was irradiated in the pile. The small grain size of the oxide allowed excellent sources to be made. A typical photogram of the tantalum with a rather weak magnetic field is shown in Fig. 2. On this plate 1 kev corresponds to a distance of about 1 mm. To cover the entire spectrum additional exposures at higher magnetic fields were made. The averaged energies from the several photographic plates are collected in Table IV, and are shown graphically in Fig. 5. On treating these energies in a manner similar to that used

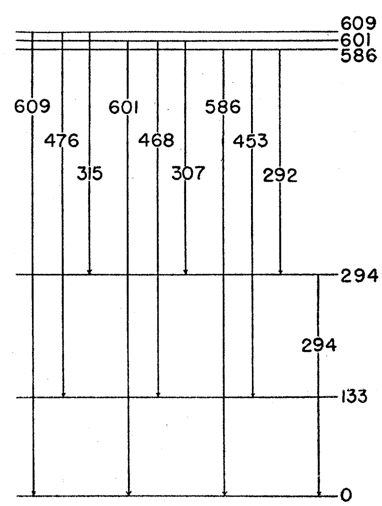

FIG. 4. A nuclear energy-level scheme for platinum* 194, following beta-emission from tantalum 194.

[3] E. McMillan, M. Kamen, and S. Ruben, Phys. Rev. **52**, 375 (1937).

[4] O. Oldenberg, Phys. Rev. **53**, 35 (1938); Science **103**, 697 (1946).

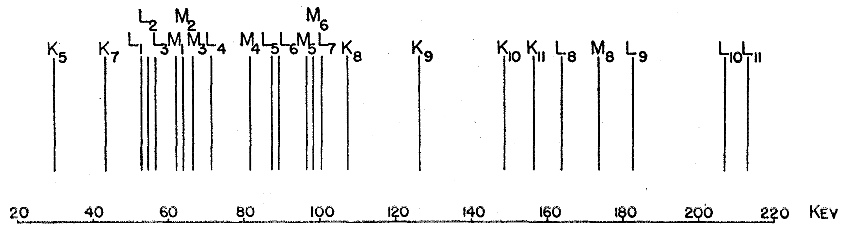

FIG. 5. The collected beta-spectrum of tantalum 182.

for the iridium an equally satisfactory solution was reached. Applying the K-L-M energy differences characteristic of tungsten to the 34 stronger lines 24 of which are shown in Fig. 5, it is possible to evaluate 16 gamma-rays as shown in Table V. Certain of the weaker lines are not used, and the interpretation of some of the lines may not be correct.

On inspecting the mathematical combinations existing between the various energies it becomes possible to arrive at an energy-level diagram as shown in Fig. 6. While some alternate scheme may work equally well it is rather amazing that so many of the observed lines are provided for, as transitions between levels, and in no case is the difference between observed and expected energy greater than one kev.

It would be desirable if the identification proposed could be substantiated by observing conversion ratios for the K, L, and M lines, compatible with a reasonable spin change, as predicted by theory. While this evidence is satisfactory in most cases, there is one notable exception. For many of the low energy gammas only the L and M lines appear, as the energy is not sufficient to eject a K electron. For the line

TABLE IV. Beta-spectrum of tantalum.

Observed energy	Identification	Gamma-energy	Observed energy	Identification	Gamma-energy
29.8 kev	K_5	99.1 kev	100.3 kev	L_7	112.4 kev
37.2	K ?	106.5	107.2	K_8	176.5
43.4	K_7	112.7	116.6	K_{15}	185.6
52.8	L_1	64.9	126.3	K_9	195.6
54.6	L_2	66.7	131.0	L_{14}	143.0
56.6	L_3	68.7	138.7	M_{14}	141.5
61.9	M_1	64.7	148.8	K_{10}	218.1
64.0	M_2	66.8	156.9	K_{11}	225.0
66.8	M_3	69.6	163.7	L_8	175.8
71.4	L_4	83.5	173.6	M_8 or L_{15}	176.4
73.5	K_{14}	142.8	182.4	L_9	194.6
81.6	M_4	83.8	190.0	K_{12}	259.3
87.2	L_5	99.3	206.2	L_{10}	218.6
89.2	L_6 or K_{16}	101.1 or 158.5	212.4	L_{11} or K_{13}	224.6 291.7
96.6	M_5	99.9	245.4	L_{12}	257.5
98.3	M_6	101.1	271.0	L_{13}	292.4

TABLE V. Summary of gamma-energies (averaged) for tantalum.

Line	Energy	Line	Energy
1	64.8 kev	9	195.1 kev
2	66.7	10	218.3
3	69.2	11	225.0
4	83.6	12	259.0
5	99.6	13	292.0
6	101.1 (?)	14	142.9
7	112.5	15	185.6
8	176.2	16	158.5 (?)

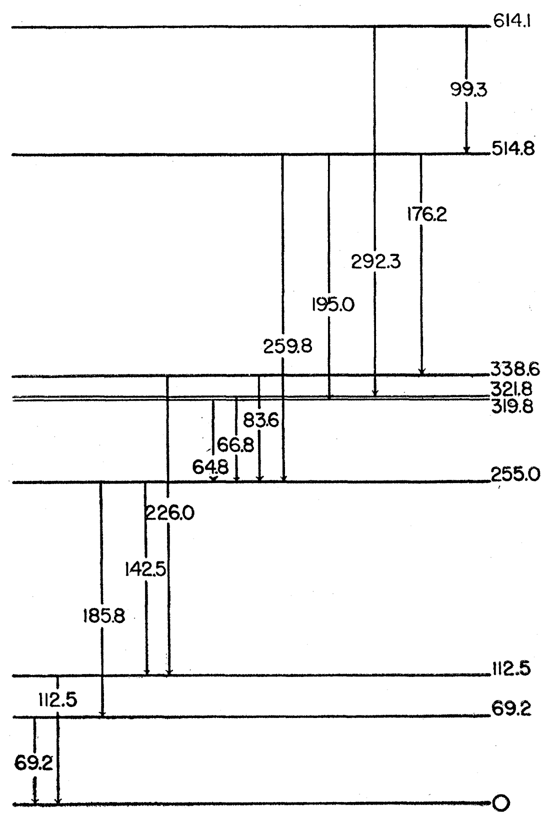

FIG. 6. Nuclear level scheme for tungsten* 182 following emission of beta-ray from tantalum 182.

designated as (5), however, the strongest line by far is the L_5, shown by legend in Fig. 2. The accompanying K line is very much weaker, although the gamma-energy is about 30 kev above the K threshold. Perhaps this energy difference is not sufficient to allow for maximum probability of K-electron emission.

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Neutron Cross-Section Studies with the Rotating Shutter Mechanism*

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It has been possible to extend the usefulness of the rotating shutter mechanism of Fermi, Marshall, and Marshall for velocity selection of neutrons by increasing the number of photoelectrically activated gate circuits. With the modifications here described data can be obtained simultaneously in six well-resolved velocity intervals. In this way the cross sections of gold, gadolinium, and dysprosium have been measured as a function of velocity for low energy neutrons.

1. INTRODUCTION

An improved velocity-selector system for low energy neutrons, giving data for six energy intervals simultaneously, has been built around the rotating shutter used by Fermi, Marshall, and Marshall.[1] The shutter consists of a series of laminae, alternately 0.006-in. thick cadmium and 0.030-in. thick aluminum, mounted axially inside a thin cylindrical steel case. As this is rotated in a neutron beam (with its axis perpendicular to the beam), two bursts of neutrons are released per revolution. Neutrons reaching a detector some distance away are registered on different scaling circuits according to the time elapsed since the shutter was open (i.e., the time of flight of the neutron). The detector used in these experiments consisted of a suitably shielded proportional counter filled with BF_3 enriched in the B^{10} isotope. The general form of the apparatus is shown in Fig. 1.

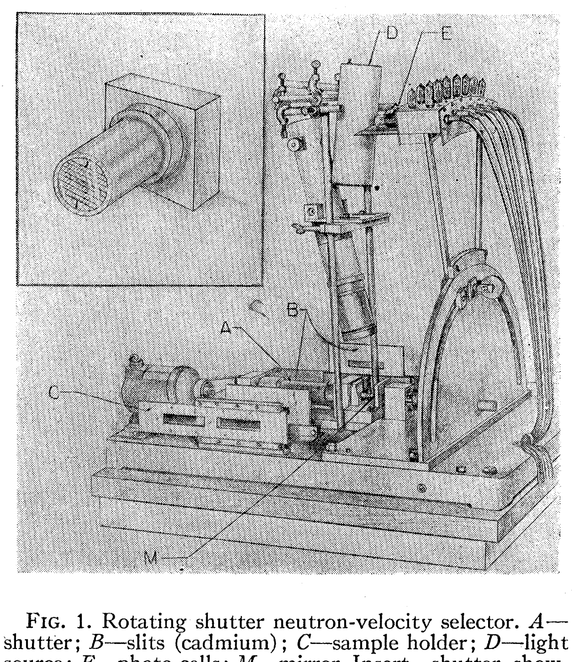

FIG. 1. Rotating shutter neutron-velocity selector. *A*—shutter; *B*—slits (cadmium); *C*—sample holder; *D*—light source; *E*—photo-cells; *M*—mirror. Insert—shutter, showing cross section. Dark areas—cadmium; crosses—aluminum; outer case—steel.

* This report is based on work done under the auspices of the Manhattan District at the Argonne National Laboratory, the University of Chicago in 1945–1946. The information contained in this document will appear in Division IV of the Manhattan Project Technical Series as a part of the contribution of the Argonne National Laboratory.

[1] E. Fermi, L. Marshall, and J. Marshall, Phys. Rev. **72**, 193 (1947).

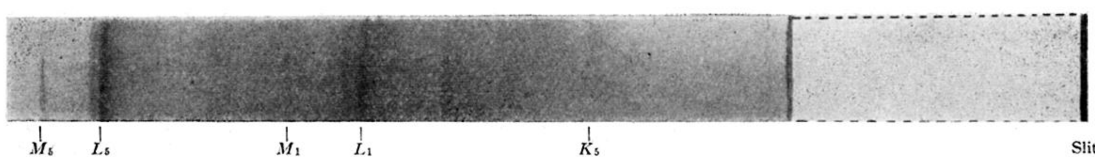

FIG. 2. Low energy portion of tantalum beta-spectrum.