The Radioactive Decay of Tungsten 187

J. M. CORK, M. K. BRICE, W. H. NESTER, J. M. LEBLANC, AND D. W. MARTIN
Department of Physics, University of Michigan, Ann Arbor, Michigan
(Received December 10, 1952)

Using sources derived from neutron capture in enriched (97.5 percent) W^{186}, about 40 internally converted electron lines are recorded in photographic magnetic spectrometers. Their interpretation leads to the evaluation of 14 gamma-rays in rhenium 187, seven of which had not been previously observed. It is possible to arrange these transitions in a consistent level scheme for the rhenium 187 nucleus. The K/L ratios are determined for five of the gamma-rays and the multipolarity and nature of the transitions proposed.

THE first observation of radioactivity in tungsten induced by slow neutrons was made in 1935, and the half-life was reported[1] to be 23 hours. Many subsequent investigations[2] have dealt with the emitted beta- and gamma-radiations and have shown the activity to be identified with the isotope of mass 187. The beta-spectrum appeared to be complex with components having maximum energies at about 0.6 and 1.3 Mev. A maximum of seven gamma-rays have been noted by various observers. The results of some of the later investigations[3-7] are shown assembled in Table I.

In the present investigation tungsten 186 was obtained from the Oak Ridge National Laboratory, enriched from its normal abundance of 29.2 percent up to 97.5 percent. The specimens were irradiated in the Argonne heavy water pile and were promptly transferred to serve as sources in photographic, magnetic spectrometers of high resolution. Throughout the complete energy range some 39 electron conversion lines have been found with energies as tabulated in Table II. These electron energies are found to fit very satisfactorily the work functions of rhenium ($Z=75$) as expected, following beta-emission from tungsten ($Z=74$). They may be interpreted to show the existence of 14 gamma-rays, seven of which had not been previously observed. For the strong low energy gamma-rays the L_1, L_2, and L_3 lines could be resolved and the M and N lines observed. For one of the gamma-rays of high energy only a K conversion line was noted. The half-life has been followed through several octaves and found to be 24.0 ± 0.1 hours, and all conversion lines decay with this same period.

The agreement between the energies found for five of the gamma-rays and the corresponding energies as expressed by DuMond *et al.*, with their high precision spectrometer, is well within our experimental error, which is believed to be not greater than ±0.2 percent. In scanning the numbers representing the gamma-energies, certain equivalent arithmetic combinations are apparent. It is thus possible, on the basis of energy values alone, to suggest a nuclear level scheme for rhenium 187. For several of the electron groups, satisfactory traces of the photographic plates could be made by a Leeds and Northrup recording microphotometer. When suitably corrected for the variation in emulsion sensitivity with energy, it is thus possible to evaluate the K/L ratios. These values as observed for particular gamma-rays are shown in column 3 of Table III. The gamma-rays are arbitrarily designated by numbers increasing with increasing energy, as shown in column 1.

TABLE I. Summary of beta- and gamma-energies of previous investigators.

Item	Investigator 3	4	5	6	7
β_1	0.6 Mev	0.65		0.63	
β_2	1.3	1.34		1.33	
γ_1				0.078	0.07200
γ_2		0.129	0.133	0.138	0.13425
γ_3			0.204		
γ_4	0.48	0.462	0.478	0.480	0.47952
γ_5	0.69	0.652	0.615	0.618	0.61889
γ_6			0.680	0.696	0.68606
γ_7			0.767		

TABLE II. Energies of electron conversion lines.

Electron energy (kev)	Interpretation	Energy sum (kev)	Electron energy (kev)	Interpretation	Energy sum (kev)
34.5	K	106.2	174.7	K	246.4
42.1	K	113.8	194.0	L_1	206.5
46.7	Auger (α_1-L_1)		203.3	M	206.2
49.0	Auger (α_1-L_3)		226.8	L_1	239.3
50.5	Auger (α_2-L_3)		234.0	L_1	246.5
59.6	L_1	72.1	408.2	K	479.9
61.6	L_3	72.1	441.8	K	513.5
62.9	K	134.6	468.0	L_2	480.0
69.4	M_2	72.1	476.4	M	479.3
71.7	N	72.3	480.0	N	480.6
94.2	L_2	106.2	547.4	K	619.1
101.4	L_1	113.9	554.0	K	625.7
111.0	M_2	113.7	606.8	L	619.3
121.8	L_1	134.3	613.5	L	626.0
122.3	L_2	134.3	614.8	K	686.5
123.6	L_3	134.1	674	L	686
131.4	M_1	134.3	702.9	K	774.6
133.5	N	134.1	763.0	L	775.0
134.6	K	206.3	794.0	K	865.7
167.5	K	239.2			

[1] McLennan, Grimmett, and Read, Nature **135**, 147 (1935).
[2] See K. Way, Nuclear Data (National Bureau of Standards Circular 499, 1950).
[3] L. Miller and C. Curtiss, Phys. Rev. **70**, 983 (1946).
[4] Hole, Benes, and Hedgran, Arkiv. Mat. Astron. Fysik **A35**, No. 35 (1948).
[5] P. Levy, Oak Ridge National Laboratory Report 312, 1949 (unpublished).
[6] Beach, Peacock, and Wilkinson, Phys. Rev. **75**, 211 (1949).
[7] Muller, Hoyt, Klein, and DuMond, Phys. Rev. **88**, 775 (1952).

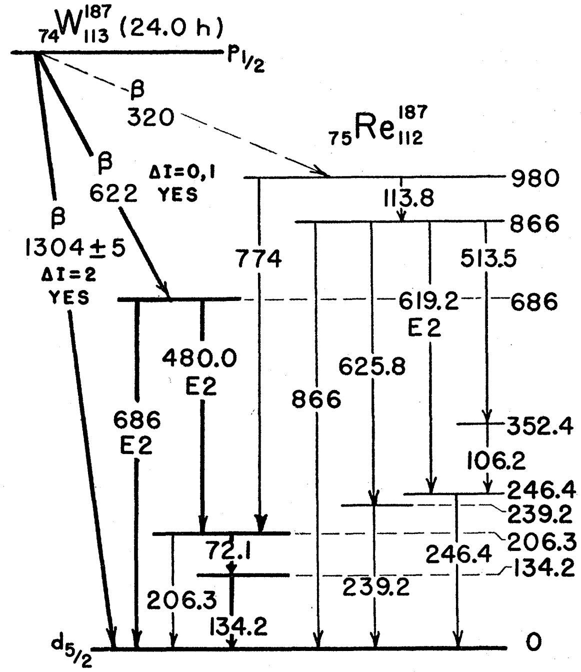

FIG. 1. Energy levels in Re[187] following β-emission in W[187].

A complementary study of the electron distribution from the tungsten specimens has been made by Mr. A. E. Stoddard in this laboratory, using the double-focusing magnetic spectrometer. From a resolution of the beta-spectrum two upper energy limits are found to be 1.304 and 0.622 Mev, with a branching ratio of 1 to 4. The 1.30-Mev beta-ray is first-forbidden with a spin change of two and a change in parity. It appears certain that no other beta-ray with an energy greater than 330 kev exists, but it is not impossible that some lower energy transition may occur. The log(ft) value for the 0.622-Mev beta-ray is 6.2, indicating that it also is forbidden with $\Delta I=0$ or 1, and a probable change of parity.

From the observed values of the K/L ratio, the radiation lifetime, and the quantity Z^2/W, where W is the energy, it is possible to employ the known empirical relationships[8] and speculate on the multipolarity and the nature of the transition for many of the gamma-rays. This information is an aid in arranging the nuclear levels in any proposed plan, such as is shown in Fig. 1. It may be noted that the placement of the curve relating K/L ratio and Z^2/W for $M2$ radiation by Goldhaber and Sunyar was based entirely upon the 134-kev

[8] M. Goldhaber and A. Sunyar, Phys. Rev. **83**, 906 (1951).

TABLE III. Gamma-energies from W[187].

Number	Energy (kev)	K/L ratio	Number	Energy (kev)	K/L ratio
1	72.1		8	480.0	4.2±0.5
2	106.2		9	513.5	
3	113.8		10	619.2	4.0±1.0
4	134.3	5.5±0.5	11	625.8	
5	206.3	4.0±0.5	12	686	5.0±1.0
6	239.2		13	774	
7	246.4		14	866	

gamma-ray in W[187]. A half-life of 5×10^{-7} sec had been observed[9] for an excited state in rhenium and the K/L ratio had been reported to be 5.1. The present observed value of 5.5±0.5 is in agreement with this. It is, however, now possible to note that the L_3/L_1 ratio is only about 1/60, which from observed[10] empirical and theoretical relationships would indicate that the transition is $M1$ or perhaps $M1$ plus $E2$.

The level arrangement shown in Fig. 1 includes as a small part, shown in heavy lines, the previously suggested order[7] for four of the gamma-rays. The observed beta-rays fit well, with an additional transition of 320 kev required. It seems quite likely that the transitions of energy 480, 619, and 686 kev are all $E2$, both from their K/L values and the fact that the L shell conversion seems to occur largely in the L_2 subshell. The delay of 5×10^{-7} second might occur in any one of several of the levels. The ground state in rhenium has been found[11] to be a $d_{5/2}$ level. While shell theory predicts for the W[187] ground state a $p_{1/2}$ level, it might have been expected that a $d_{3/2}$ state would exist as was found[12] for the very similar nucleus, osmium 189. This would, however, be incompatible with the beta-transition of maximum energy being first-forbidden. It is not possible to assign spin values to all levels on the basis of present information.

This project received the joint support of the U. S. Atomic Energy Commission and the U. S. Office of Naval Research.

Note added in proof:—The electron line at 480 kev could also be interpreted as a K line for a gamma-ray at 552 kev, as observed by Sunyar [Bull. Am. Phys. Soc. **28**, Z3 (1953)] by a scintillation method. It fits the scheme of Fig. 1 as a transition between the levels at 134.2 and 686 kev.

[9] McGowan, DeBenedetti, and Francis, Phys. Rev. **75**, 1761 (1949); Bunyan, Lunby, and Walker, Proc. Phys. Soc. (London) **A62**, 253 (1949).
[10] J. Mihelich, Phys. Rev. **87**, 646 (1952).
[11] Meggers, King, and Bacher, Phys. Rev. **38**, 1258 (1931).
[12] K. Murakawa and S. Suwa, Phys. Rev. **87**, 1048 (1952).