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Radioactivity in Hafnium*

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A LONG-LIVED radioactivity in Hf^{181} activated by slow neutrons was first observed[1] by Hevesy and Levi and reported as having a half-life of 55 days. Subsequent spectrometric studies of similar specimens irradiated in the Oak Ridge pile showed[2] the presence of four internally converted gamma-rays. A level scheme utilizing these gamma-rays, but with divergent energy values, was proposed[3] by Wiedenbeck and Chu.

Continued investigation of other specimens now allows a more accurate evaluation of previously reported energies and reveals many electron lines not observed previously. These electron energies as obtained by internal conversion and by photo-emission from lead are presented in two groups. In Table I are those electron

Table I. Electron energies identified.

Electron energy	Identification	Energy sum
25.7 kev	K(Lu)	89.1 kev
65.2	K^1	132.4
68.5	K^2	135.7
77.8	L(Lu)	88.1
85.5	M(Lu)	87.9
121.7	$L_{1,2}{}^1$	132.8
123.0	$L_3{}^1$	132.9
124.5	L^2	135.6
130.3	M^1	133.0
132.1	N^1	132.7
133.5	M^2	136.2
277.3	K^3	344.5
278.9	K(Lu)	342.3
331.4	L(Lu)	341.7
340.0	M(Lu)	342.4
414.0	K^4	481.2
469.5	L^4	480.6
478.0	M^4	480.7
543.8	K^5	612.0

lines whose identification seems to be established beyond question. In Table II the remaining 13 electron lines are listed. These latter lines are so numerous and so closely spaced as to energy that their interpretation at the present time is not unique.

A short-lived activity (10.2 hr.) previously unreported, appeared to exist in the pure specimen. The half-life associated with the beta-decay of Hf^{181} is here followed through five octaves and found to be 45 days. The associated gamma-rays following beta-emission would be in tantalum ($Z=73$). The K–L–M differences observed for most of the strong electron lines are characteristic of tantalum as shown in Table I, yielding five gamma-rays whose energies are 132.7, 135.7, 344.5, 481.0, and 612 kev and assigned arbitrary numbers in the order of increasing energy. These energies fit almost perfectly on the amended level scheme of Wiedenbeck and Chu as shown in Fig. 1. By the use of a coin-

Table II. Electron energies not positively identified.

Electron energy	
127.0 kev	146.0 kev
135.0	148.7
137.0	193.8
139.0	197.5
141.0	199.7
142.5	203.2
144.5	

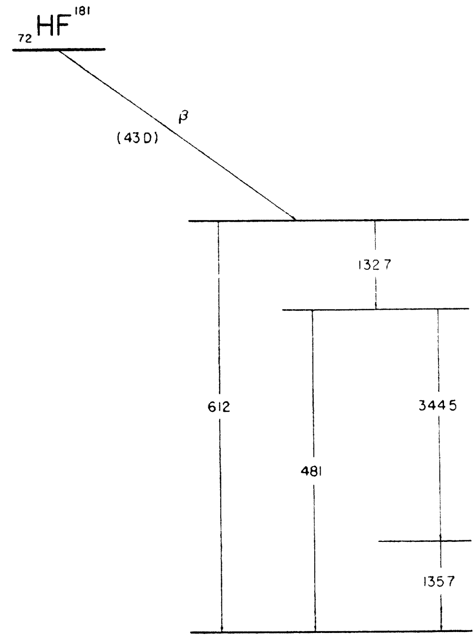

Fig. 1. Energy levels in Ta^{181}, following beta-emission from Hf^{181}.

cidence magnetic beta-spectrometer (to be described elsewhere) Dr. R. G. Shreffler has shown conclusively that the 132.7 kev and the 135.7 kev lines are in sequence with the 344.5 kev line but the coincidence rate is greater for the latter two than for the first and last lines. The 481 kev line is found to be in coincidence with the 132.7 kev line but not with the 344.5 kev line. This behavior is exactly as would be expected in the branching scheme of Fig. 1. The K/L conversion ratios are about one for γ_1 and only about one-fifth for γ_2.

Hf^{175} could be produced in the pile by neutron capture in Hf^{174} (0.18 percent) or by the (n,2n) reaction of Hf^{176} (5.3 percent). This isotope would decay by K-capture to Lu^{175} ($Z=71$) and has been reported[4] to have a half-life of 70 days, and to emit a gamma-ray whose energy by absorption in lead was 350 kev. Two groups of the electron lines shown in Table I have K–L–M differences characteristic of lutecium and yield gamma-energies of 88.7 and 342.1 kev. Many of the electron lines in Table II can equally well be interpreted as due to gamma-rays in lutecium. There is no evidence however, of a 70 day half-life component in the specimens here studied. On aging beyond the 45-day activity a remaining relatively strong activity persists whose half-life appears to be greater than one year. This problem can ultimately best be resolved by the use of enriched stable isotopes.

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Excitation Curve for Protons in the Reaction $F^{19}(d,p)F^{20}$ *

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THE total cross section for the production of protons in the reaction

$$F^{19}+H^2\rightarrow F^{20}+H^1 \quad (1)$$