Energy Levels of Hf^{177}†

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(Received September 3, 1954)

The nuclear spectrum of Lu^{177} has been investigated. Three excited levels of Hf^{177} have energies of 112.97 kev, 249.69 kev, and 321.33 kev. A decay scheme is proposed.

THE decay of 6.8-day Lu^{177} has been studied with the curved-crystal γ-ray spectrometer and the axial-focusing β-ray spectrometer. High specific activity Lu^{177} was produced by irradiation of 1.5 mg of lutecium chloride in the Arco reactor.[1] A source of about 200 mC was used in the γ-ray spectrometer and several weak β-ray sources were prepared by evaporation. The momentum resolution obtained with the β-ray spectrometer was 0.15 percent.

In addition to the well-known lines at 113 kev, 208 kev, and 321 kev, weak lines were found at 72 kev and 250 kev (Table I). The conversion coefficients of the 113-kev and 208-kev transitions show that they are, respectively, $E2$ and $E1$ transitions, in agreement with the results of McGowan *et al.*[2] From the L-conversion data (Fig. 1) it can be concluded that the 113-kev transition has pure $E2$ character, the upper limit of an $M1$ admixture being 2 percent. The conversion coefficient of the 321-kev crossover line indicates an $E3$ or $M1$ transition, rather than an $E1$. In order to agree with the requirement of parity change indicated by the multipolarity of the 113-kev and 208-kev lines, the $M1$ possibility must be eliminated. No conversion electrons of the 72-kev line could be detected. The small conversion probably indicates an $E1$ transition. The 250-kev line is strongly converted and is probably an $M1$ transition.

The ordering of the energy levels was established by coincidence measurements between γ rays and β-spectrum electrons, using a scintillation detector mounted at the source end of the β spectrometer for the detection of the photons. The end point of the spectrum going to the 321-kev level is 176-kev ($\log ft=6.3$) and that of the spectrum going to the 113 kev level is 384 kev ($\log ft=7.7$). The most intense spectrum leads to the ground state. Its upper limit has been found at 497 ± 2 kev, ($\log ft=6.8$) in agreement with the results of Douglas.[3] The 72-kev and 250-kev lines were too weak to permit coincidence work in the β spectrometer. Using

TABLE I. γ transitions in Hf^{177}.

Energy (kev)	Relative γ intensity	Absolute conversion coefficients α_K	α_{LI}	α_{LII}	α_{LIII}	Decay fraction percent	Multipolarity
71.644±0.020	2	···	···	···	···	0.1	($E1$)
112.965±0.020	100	0.75	0.12	0.70	0.58	10	$E2$
208.362±0.020	220	0.044	0.007	···	···	7	$E1$
250.0 ±0.5	3	0.3	0.1	···	···	0.1	($M1$)
321.36 ±0.10	3.2	0.2	···	···	···	0.1	($E3$)

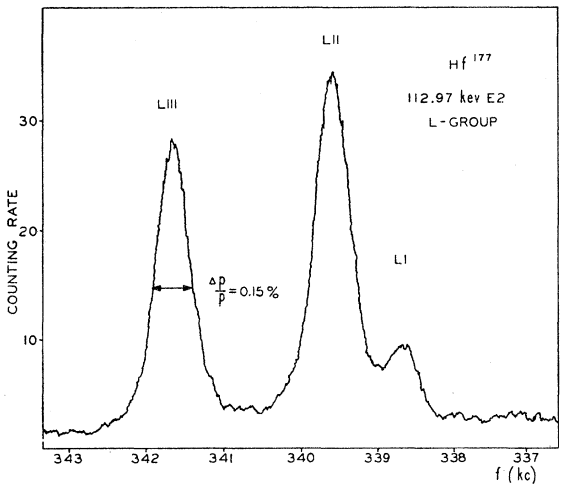

FIG. 1. L-conversion spectrum of the 113-kev line.

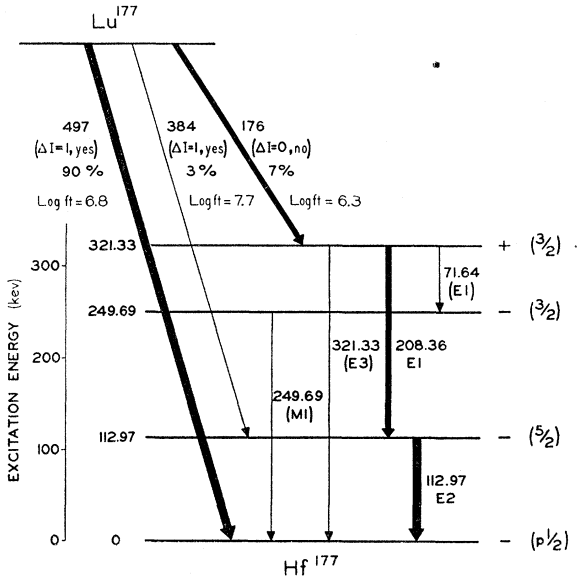

FIG. 2. Proposed energy level scheme for Hf^{177}. Data in parentheses ( ) are uncertain.

† Assisted by contracts with the U. S. Atomic Energy Commission and the Office of Ordnance Research (U. S. Army).
[1] We wish to thank Dr. R. B. Day, Los Alamos Scientific Laboratory, who suggested these measurements and made the arrangements for procurement of the source.
[2] McGowan, Klema, and Bell, Phys. Rev. **85**, 152 (1952).
[3] D. G. Douglas, Phys. Rev. **75**, 1960 (1949).

two scintillation spectrometers in coincidence it was however possible to show that the two lines are in cascade. The 250-kev line might be identical with the one reported by Temmer and Heydenburg,[4] found by Coulomb excitation of an odd Hf isotope.

The proposed decay scheme appears in Fig. 2. The intensity ratio of the 72-kev and 208-kev lines is in agreement with the value expected from the theoretical lifetime relation.[5] On the same basis, however, the relative intensity of the 321-kev line is much larger than that expected for an $E3$ transition. No transition was observed between the 250-kev and 113-kev levels.

According to their ft value, spin and parity change, the three β spectra can be classified as allowed, $\Delta I=0$, no (176 kev); first forbidden $\Delta I=1$, yes (384 kev); and first forbidden $\Delta I=1$, yes (497 kev). The spin of the ground state of Hf^{177} is either $\frac{1}{2}$ or $\frac{3}{2}$.[6] The shell model predicts a $p_{\frac{1}{2}}$ configuration,[7] which is used as a basis for the tentative spin assignment in Fig. 2. According to McGowan's angular correlation experiments[2] the 208-kev—113-kev dipole-quadrupole cascade involves a spin change of $+1$ and -2 units and a spin 7/2 for the intermediate level (113 kev). A spin 5/2 for this level, however, would not be in serious contradiction with McGowan's results. One finds then a spin $\frac{3}{2}$ and even parity for the ground state of Lu^{177}, which is not in contradiction with the predictions of the shell model.

We would like to acknowledge the interest of Professor Jesse W. M. DuMond in this work. We are indebted to Mr. E. Hatch and Mr. P. Snelgrove for their help during the measurements.

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PHYSICAL REVIEW VOLUME 97, NUMBER 1 JANUARY 1, 1955

Angular Distribution of Gamma Rays from Proton Capture in B^{11}

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(Received September 2, 1954)

The γ-ray yield at 90° from the bombardment of B^{11} by protons shows resonances for proton energies of 0.67, 1.4, and 2.7 Mev. The angular distributions of the two γ rays of high energy, $\gamma_0\sim17$ Mev and $\gamma_1\sim12$ Mev, have been measured at these resonances to obtain evidence concerning the spins and parities of the excited nucleus. The evidence favors 2− for the 0.67-Mev resonance, 1− for that at 1.4 Mev, and 2+ at 2.7 Mev, but these assignments cannot be made with certainty.

I. INTRODUCTION

THE most recent and most complete investigation to date on the capture gamma radiation from proton bombardment of B^{11} is that of Huus and Day.[1] A brief summary of this work follows. Using a sodium iodide scintillation counter they have examined the gamma-ray spectrum and find the capture gamma rays which occur in a direct transition to the ground state of C^{12} and in a cascade through the 4.44-Mev level in C^{12}. Yield curves for the transition to the ground state ($h\nu\sim17$ Mev) and to the first excited state at 4.44 Mev ($h\nu\sim12$ Mev) were measured at 90° at proton energies from 0.15 Mev to 2.8 Mev. Cross sections for the various gamma rays were also measured. In addition to the well-known resonance at 0.163 Mev, resonances were observed at 0.675 with $\Gamma=0.33$ Mev and at 1.388 with $\Gamma=1.27$ Mev. Spins and parities of these states are deduced from these measurements and measurements of the $B^{11}(p,\alpha)Be^8$ reaction made by Beckman, Huus, and Zupančič[2] to be 2− or 3+ for the 0.675 resonance and 1− for the 1.388 resonance. The latter result is based primarily on single-particle limit[3] and radiation width[4] considerations. In addition, the yield curve for a 2.13-Mev gamma ray produced in an inelastic scattering reaction involving the first excited state of B^{11} was observed and showed a resonance at 2.664 Mev with a width of 48 kev. A comprehensive list of references to previous work in this field is contained in the paper of Huus and Day.

Recently some measurements on the angular distributions of the ground and first excited state gamma transitions have been reported[5] by Givin *et al.*

The work to be reported here comprises measurements of the yield curve at 90° to the proton beam of the capture gamma rays in the range of proton energies between 0.55 and 2.85 Mev. In addition, their angular distributions have been measured at several energies in this range.

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