TABLE I. Experimental and theoretical K-shell conversion coefficients.

Nucleus	E_γ, kev	$T_{1/2}$, sec	$\alpha_{exp}{}^K$	$(\alpha_2{}^K)_{extrap}$
$_{66}Dy^{160}$	85	1.8×10^{-9}	1.65 ± 0.2	1.75
$_{67}Ho^{165}$	95	$<.8\times10^{-9}$	$\lesssim 2.9$	1.40
$_{68}Er^{166}$	81	1.7×10^{-9}	1.9 ± 0.3	1.94
$_{70}Yb^{170}$	85	1.6×10^{-9}	1.5 ± 0.2	1.65

percent which justifies the foregoing procedure at least for electric dipole, quadrupole, and magnetic dipole.

The extrapolated K-shell conversion coefficients for electric quadrupole radiation are listed in Table I. Corresponding values for electric dipole and magnetic dipole radiation are about 4 times smaller and 3.5 to 7 times larger than $\alpha_2{}^K$, respectively.

In the case of Dy^{160}, Er^{166}, and Yb^{170}, the isomeric transitions are to the ground state in even-even nuclei which presumably have spin zero and therefore only pure multipole radiation is possible. Thus, these transitions are of the $E2$ type and the spin of the excited state is two.

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Classification of the γ-Radiation of Hf^{177}

F. K. McGowan, E. D. Klema, and P. R. Bell
Oak Ridge National Laboratory, Oak Ridge, Tennessee
(Received November 16, 1951)

THREE γ-rays of Hf^{177} following the β^--decay of Lu^{177} are classified, and the angular momentum and relative parity of the nuclear states are assigned by measurements of the directional angular correlation of successive gamma-quanta and the K-shell internal conversion coefficients.

The 6.7 day Lu^{177} β^--activity is known to decay by three beta-groups to Hf^{177}.[1] The lowest energy beta-group leads to an excited state in Hf^{177} followed by two γ-rays in cascade with energies 206 and 112 kev.

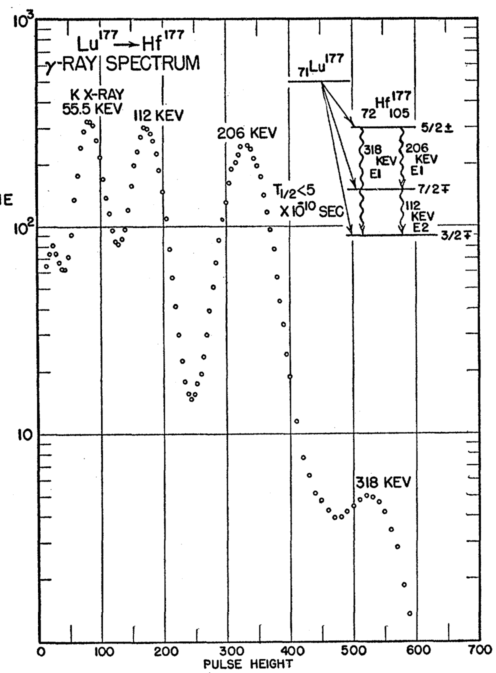

FIG. 1. Spectrum of the γ-radiation following the β^--decay of Lu^{177}.

The half-life of the excited state at 112 kev above the ground state is $T_{\frac{1}{2}}<5\times10^{-10}$ sec as measured with a delayed coincidence scintillation spectrometer using anthracene detectors. The γ-ray spectrum has been examined with a NaI scintillation spectrometer and is shown in Fig. 1. The spectrum was taken at such a geometry that the 318-kev peak is due to the 318-kev crossover transition alone. The peaks have been resolved into Gaussian components and the intensity of the crossover transition from the 318-kev excited state is (4.5 ± 0.5) percent.

Since the lifetime of the intermediate state at 112 kev is sufficiently small, the 206- and 112-kev γ-ray cascade appeared to be an ideal case in which to investigate the directional angular correlation of successive gamma-quanta. The angular correlation, measured with a coincidence scintillation spectrometer using NaI detectors, is found to be anisotropic. The γ-rays entering in the angular correlation measurement are selected according to their energy. One detector selects the 206-kev γ-radiation and the other detector the 112-kev γ-radiation. The coincidence resolving time is 10^{-7} sec and the angular resolution is $\pm12.7°$. Under these conditions the true coincidence rate is of the order of 2.5 counts/sec while the random rate is 8 percent of this. Figure 2 shows the

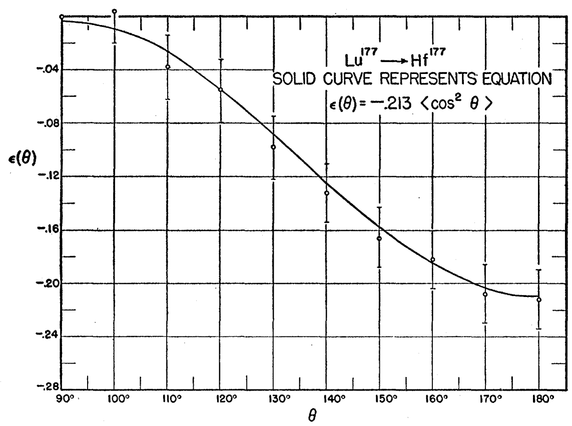

FIG. 2. Directional angular correlation of the 206- and 112-kev γ-ray cascade from Hf^{177}.

observed angular distribution. The ordinate represents

$$\epsilon(\theta)=[n(\theta)-n(\tfrac{1}{2}\pi)]/n(\tfrac{1}{2}\pi)=W(\theta)-1, \qquad (1)$$

where

$$W(\theta)=1+\sum_{i=1}^{n} a_{2i}\cos^{2i}\theta.$$

The solid curve represents $\epsilon(\theta)=-0.213\cos^2\theta$, where $\cos^2\theta$ has been averaged over the finite angular resolution of the apparatus. $W(\theta)=1-0.213\cos^2\theta$ is characteristic of a dipole-quadrupole cascade with angular momenta $5/2\rightarrow7/2\rightarrow3/2$ for the three states in order of decreasing excitation energy. Other dipole→quadrupole combinations with the correct magnitude $(a_2=-0.21\pm0.02)$ of the anisotropy may be excluded either on the basis of the observed shape of the angular correlation distribution or from the requirement that the ground state be restricted to $J\leq3/2$.[2] The measured contribution of the 318-kev transition by a Compton scattering between the two detectors is 0.01 percent of the true coincidence rate.

By measuring the intensity ratio of the K x-ray to the γ-ray in coincidence with the other γ-ray of the cascade, one obtains the K-shell internal conversion coefficient of each γ-ray in the cascade. The observed intensity ratio must be corrected for fluorescent yield,[3] escape peak intensity, fraction of the detected γ-rays appearing in the full energy peak, and effective detection efficiency. These are tabulated in Table I. The experimental error for $\alpha^K(206)$ is rather large because there is the additional interference from back-scattered photons by the Compton process from one detector

TABLE I. Experimental results and correction factors.

E_γ	Observed intensity ratio	Fluorescent yield W_K	Escape peak intensity for x-ray	Detected γ-rays in full energy peak	Detection efficiency ratio $\epsilon_\gamma/\epsilon_x$	$\alpha^K{}_{\text{exp}}$
112 kev	0.69	0.937	0.15	0.98	0.95	0.81 $\pm$0.08
206	0.046	0.937	0.15	0.92	0.80	0.042 $\pm$0.015

to the other. Some measurements were taken with a Pb-Cd diaphragm between the detectors to reduce the back-scattering. Typical coincidence counting rates at the peaks in the measurement of $\alpha^K(112)$ are 30 counts/sec while the random rate is 0.5 percent of this.

The experimental and theoretical internal conversion coefficients[4] are compared in Table II. From the internal conversion coefficient data one concludes that the 206- and 112-kev transitions are of the $E1$ and $E2$ type, respectively. It appears that both the internal conversion and the directional angular correlation data are consistent with the interpretation that both transitions are pure multipoles.

TABLE II. Experimental and theoretical internal conversion coefficients.

E_γ	$\alpha^K{}_{\text{exp}}$	$\alpha_1{}^K$	$\alpha_2{}^K$	$\beta_1{}^K$
112 kev	0.81 $\pm$0.08	0.22	0.80	2.8
206	0.042 $\pm$0.015	0.045	0.153	0.52

A proposed level scheme for Hf^{177} is shown in Fig. 1. Mayer's strong spin orbit coupling shell model[5] would predict either a $p_{\frac{3}{2}}$ or $f_{\frac{5}{2}}$ orbit for Hf^{177} with $N=105$. Although relative parities are indicated in Fig. 1, the shell model predicts the ground state to be odd parity. In this case the parities of the excited states would be odd and even in order of increasing excitation energy. The even parity for the state at 318 kev is in contradiction to the shell model, which would predict odd parity orbits except for $i_{13/2}$ orbits for N odd between 83 and 125. The occurrence of two $E1$ transitions is also in contradiction to the shell model. The $E1$ crossover transition of 318 kev should compete favorably with the 206-kev transition, but the observed intensity ratio is 80 times smaller than the theoretical estimates from transition probability-energy relations.[6] Thus, one should use the estimates for transition probabilities between states in a given nucleus with extreme caution for estimating intensities of crossover transitions.

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The Isomeric Transition in Ge^{77}*

ALLAN C. G. MITCHELL AND ALAN B. SMITH
Indiana University, Bloomington, Indiana

(Received November 5, 1951)

THE nucleus Ge^{77} decays to As^{77} *via* a beta-ray transition of 12-hour half-life and also by a beta-ray transition of 59-sec half-life. The isomeric states, 59-sec and 12-hour, occur in the parent nucleus. Ge^{77} has 45 neutrons and, according to the older version of the shell model, the two states responsible for the isomeric transition should have configurations $p_{1/2}$ and $g_{9/2}$. Recent considerations[1] show, however, that for 3, 5, 7 neutrons beyond neutron number $N=38$ the states may be $G_{7/2}$ and $p_{1/2}$.

The present work stems from an investigation of the spectrum of the 12-hour Ge^{77} which is nearing completion in the laboratory, and will be published shortly. The spectrum of the 12-hour Ge^{77} is complicated, but we have shown that the highest energy beta-ray group has an end-point energy of 2.2 Mev and leads to an excited state of As^{77} 0.263 Mev above the ground state. The energy of the 12-hour Ge^{77} is therefore 2.46 Mev above the ground state of As^{77}. Arnold and Sugarman[2] have excited the 59-sec isomeric state and measured the beta-ray end point by absorption. They obtain an energy of 2.8 Mev. One would, therefore, expect the isomeric states to have a difference in energy of approximately 0.34 Mev.

In the present experiment a piece of germanium metal was bombarded for 1.5 minutes with slow neutrons from the cyclotron. It was then examined with the help of a scintillation spectrometer by the photographic method of Hofstadter and McIntyre.[3] Figure 1 shows pictures of the envelope of the oscillograph traces taken with a Polaroid Land Camera. The exposure time of each picture was one minute and the procedure was such that the exposure of each picture was started 2 minutes after the start of the previous picture. An inspection of Fig. 1 shows that the radiation decays with a half-life of about 1 minute. The energy of the gamma-ray, obtained by measuring the height of the pulse envelope and comparing this with the 0.661 gamma-ray of Cs^{137}, is 380$\pm$20 kev. This is in good agreement with the energy of the transition as determined by the previously mentioned absorption and spectrometric work.

From these experiments and those on the decay of the 12-hour Ge^{77} it is possible to obtain the configurations of the two states of Ge^{77}. The upper state (59-sec) is $p_{1/2}$, since it goes to the ground state of $As^{77}(p_{3/2})$ with the emission of a beta-particle for which $\log ft=4.8$. The lower state (12 hr) goes *via* a beta-transition to an excited state of As^{77}. This transition shows a $\log ft=7.6$ and has an allowed shape. The first excited state of As^{77} is probably $f_{5/2}$.

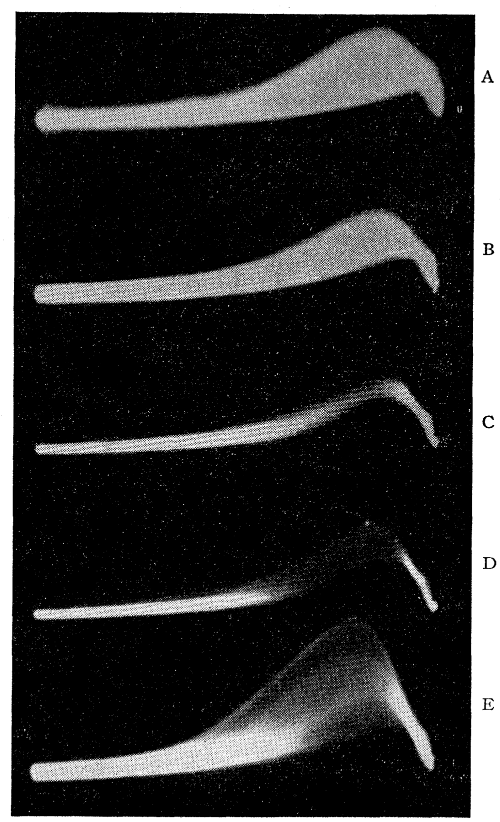

FIG. 1. Isomeric state of Ge^{77} (from top to bottom): A—bombardment +0.5 min; B—bombardment +2.5 min; C—bombardment +4.5 min; D—bombardment +6.5 min; and E—Cs^{137} for calibration.