determined by the proton spectra under investigation, on three of the plates an alpha-particle group was observed which, from its shift in energy, has been assigned to the V^{51}(p,α)Ti^{48} reaction. The Q-value for this group is 0.167±0.010 Mev. On one of the exposures, a higher energy alpha group was also observed. This group was not recorded at the other energies and angles, as was to be expected if it also is from the V(p,α) reaction. On this assumption, its Q-value is 1.161±0.010 Mev. While the masses in this region are not known to a sufficient accuracy to determine whether this is the ground-state group, it seems probable that this is the case and that the other group is from the first excited state of Ti^{48}. The energy of this state, as determined from measurements on the decays of Sc^{48} and V^{48}, is 0.990 Mev[1,21] in good agreement with the value obtained by taking the difference between the Q-values.

It is a pleasure to acknowledge our continued indebtedness to Mr. Wilton A. Tripp for the measurements on the nuclear track plates and to our colleagues for much helpful assistance.

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[21] Casson, Goodman, and Krohn, Phys. Rev. 92, 1517 (1953).

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Nuclear Levels of Lu^{175}†*

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The negatron decay of Yb^{175} (4.2 day) and orbital electron capture decay of Hf^{175} (70 day) to Lu^{175} have been investigated in detail using a magnetic lens spectrometer, 180° permanent magnet spectrographs, scintillation spectrometers, and coincidence techniques. Eleven gamma transitions in Lu^{175} of the following energies and indicated multipolarities have been observed: 89.3 ($M1+E2$), 113.6 ($M1+E2$), 137.6, 144, 229.3 ($E2$), 251, 282.4 ($E1+M2$), 318.6, 342.9 ($M1+E2$), 396.0 ($E1+M2$), and 432.2 kev. On the basis of these measurements, consistent decay schemes for Yb^{175} and Hf^{175} are proposed. Observed nuclear levels in Lu^{175} excited by the radioactive decay of these two nuclides occur at 113.6, 251.2, 342.9, 396.0, and 432.2 kev and are assigned spin and parity values 9/2+, 11/2+, 5/2+, 9/2−, and 5/2+, respectively. The levels at 113.6 kev and 251.2 kev constitute a rotational band whose base state occurs at stable Lu^{175} (7/2+).

I. INTRODUCTION

LUTECIUM-175, daughter nucleus of Yb^{175} and Hf^{175}, has a measured ground-state spin of 7/2.[1] According to the formulation for collective rotational motion in highly deformed nuclei,[2] Lu^{175} should thus be expected to exhibit a well-developed rotational structure, and, indeed, what appear to be rotational levels have recently been observed in this nuclide by means of Coulomb excitation.[3] It therefore becomes of interest to apply nuclear spectroscopy techniques, i.e., study of the radiations of Yb^{175} (4.2 day), and Hf^{175} (70 day) to investigate in greater detail, if possible, the characteristics of the rotational transitions in Lu^{175}. In addition there exist features in the previously studied decay schemes of Yb^{175} and Hf^{175} which demand further clarification.[4] Therefore, a detailed reinvestigation of the radioactive decay of these two nuclides has been performed.[5]

II. DECAY OF Yb^{175}

(a) Source Preparation

Yb^{175} was prepared by thermal neutron bombardment of Yb$_2$O$_3$ [6] of natural isotopic abundance. Fractions of Yb^{169} (32-day) and Yb^{177} (1.8-hr) were also activated in the irradiation. All studies reported herein were performed after the Yb^{177} had essentially decayed to Lu^{177} (6.8-day). The quantity of Lu^{177} thus activated was found to be innocuous as far as the study of the Yb^{175} decay was concerned. The gamma activity accompanying the decay of the orbital electron capture isotope Yb^{169}, however, had to be carefully taken into account throughout the Yb^{175} experiments. Fortunately the relatively long half-life of Yb^{169} as compared to that of Yb^{175} enabled an unambiguous separation of the emanations of the two isotopes to be realized.

(b) Gamma-Ray Experiments

The results of a study of the gamma-ray spectrum engendered by the radioactivity produced through thermal neutron bombardment of Yb$_2$O$_3$ is shown in Fig. 1. The spectrum was obtained with a $1\frac{1}{2}\times1\frac{1}{2}$ inch NaI(Tl) crystal mounted on a Du Mont 6292 photomultiplier tube. A ten-channel analyzer was used for

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† Work performed under the auspices of the U. S. Atomic Energy Commission.

* A report of this work was presented at the 1955 Washington Meeting of the American Physical Society [Mize, Bunker, and Starner, Phys. Rev. 99, 671(A) (1955)].

[1] J. E. Mack, Revs. Modern Phys. 22, 64 (1950).

[2] A. Bohr and B. R. Mottelson, Kgl. Danske Videnskab. Selskab., Mat.-fys. Medd. 27, No. 16 (1953).

[3] N. P. Heydenburg and G. M. Temmer (to be published).

[4] Hollander, Perlman, and Seaborg, Revs. Modern Phys. 25, 469 (1953).

[5] Following completion of the Yb^{175} experiments described below, accounts of studies of the Yb^{175} decay scheme were published by N. Marty, Compt. rend. 240, 963 (1955); H. De-Waard, Phil. Mag. 46, 445 (1955); Akerlind, Hartmann, and Wiedling, Phil. Mag. 46, 448 (1955).

[6] The Yb$_2$O$_3$ of specified purity 99.95% was obtained from Johnson, Matthey and Company, Limited, Hatton Garden, London.

TABLE I. Gamma transitions of Yb^{175}.

Gamma energy (kev)	Relative gamma intensities	Relative transition intensities	α_K	$L_I:L_{II}:L_{III}$	$K/(L+M)$	Multipolarity
113.6	7 ± 1	22 ± 3	1.7 ± 0.4	3:1:1	...	$E2/M1=0.30\pm0.06$
282.4	10 ± 2	10 ± 2	0.038 ± 0.01	...	$\geqslant5$	$M2/E1=0.027\pm0.016$
396.0	23 ± 3	23 ± 3	0.050 ± 0.005	...	5.8 ± 0.5	$M2/E1=0.20\pm0.03$
137.6	<1	<1	...	...	...	$(M1+E2)$[a]
144	<2	<2	...	...	...	$(E1)$
251	<1	<1	...	...	...	$(E2)$[a]

[a] Multipolarity assignment deduced from decay scheme of Fig. 5(a).

the recording of data. The decay of the gamma spectrum of Fig. 1 was followed for 40 days, and it was established that the 114-, 282-, and 396-kev gammas decay with a half-life of ~4.2 days, characteristic of Yb^{175}. The photon peak (A) of Fig. 1 was attributed to 178- and 198-kev gamma rays of Yb^{169}.[4] The relative intensities of the 114-, 282-, and 396-kev gammas were measured with a 2×2 inch NaI(Tl) crystal whose detection sensitivity (photopeak area *vs* energy) is empirically known. The gamma intensity data are summarized in Table I.

On the basis of the above energy values, it appeared likely that the 114- and 282-kev gamma rays are in coincidence and that the 396-kev gamma is a crossover transition. Therefore, a gamma-gamma coincidence experiment was performed in which the 282-kev photopeak was used as the "gate" and a one-hundred channel pulse-height analyzer[7] was used to record the coincidence spectrum. The resolving time of the coincidence apparatus was $2\tau=0.4$ microsecond. A strong photopeak was observed at 114-kev, only a few percent of which resulted from chance coincidences, and thus the 114-kev to 282-kev coincidence was verified.

In order to position a 137.6-kev transition of Yb^{175} which was observed with a 180° magnet spectrograph and which is discussed in Sec. IIc, a series of gamma-gamma coincidence experiments was performed. To avoid coincidences resulting from Compton scattered quanta, a $\frac{1}{4}$ inch thick piece of lead was placed between the two NaI(Tl) crystals of the coincidence scintillation spectrometer. The axes of the crystals were oriented at 20 degrees with respect to each other. With the "gate" channel set to cover the 90- to 170-kev region, the one-hundred channel analyzer recorded the presence of two photopeaks in the coincidence spectrum at 114 and 140 kev as shown in Fig. 2. When the "gate" channel was set to cover the 140-kev region, a 140-kev photopeak was observed in the coincidence spectrum which indicated that the 140-kev photopeak is engendered by a multiplet of coincident gamma rays. Furthermore, a 251-kev gamma ray was observed to be in coincidence with a gamma in the 140-kev region. A coincidence experiment in which the 220- to 280-kev region was utilized as a "gate" demonstrated that a 144-kev transition is in coincidence with the 251-kev transition (Fig. 3). The occurrence of the 114-kev photopeak in Fig. 3 is attributable to the unavoidable inclusion in the "gate" of a portion of the 282-kev gamma spectrum.

From the foregoing coincidence experiments, it was concluded that a 144-, 137.6-, 114-kev triple gamma cascade exists in the Yb^{175} decay with a 251-kev gamma being in coincidence with the 144-kev gamma and serving as a crossover transition of the 137.6-kev to 114-kev cascade. Although further coincidence experiments were performed, no additional coincident gamma transitions were found to accompany the Yb^{175} decay.

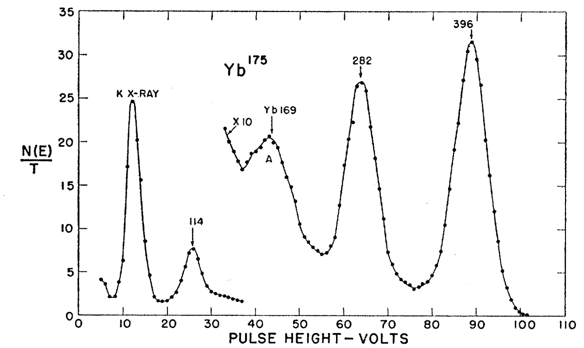

FIG. 1. Gamma-ray spectrum of Yb^{175} obtained with a $1\frac{1}{2}$ inch $\times1\frac{1}{2}$ inch NaI(Tl) crystal. The high-energy region is shown on an enlarged scale (×10).

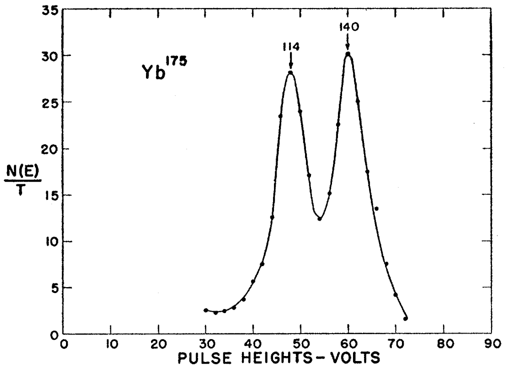

FIG. 2. Gamma-ray coincidence spectrum obtained with the "gate" channel set to accept pulses in the energy range 90 to 170 kev.

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[7] P. W. Byington and C. W. Johnstone, *A One-Hundred Channel Pulse Height Analyzer Using Magnetic Core Storage* (to be published in the I.R.E. Convention Record, 1955).

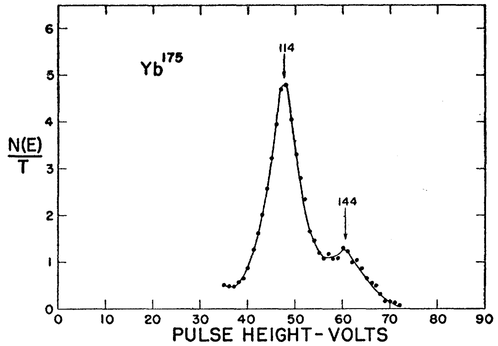

FIG. 3. Gamma-ray coincidence spectrum obtained with the "gate" channel set to accept pulses in the energy range 220 to 280 kev.

The results of the coincidence experiments are embodied in the decay scheme of Fig. 5(a).

Throughout the coincidence experiments, the gamma rays accompanying Yb^{169} decay had to be carefully distinguished from those belonging to Yb^{175}. To accomplish this separation, all coincidence experiments had to be performed twice, once with a fresh source having a large Yb^{175}/Yb^{169} activity ratio and again with a source having a large Yb^{169}/Yb^{175} ratio. Because of the relative half-lives of Yb^{175} and Yb^{169}, these two types of sources were readily available. Thus, by comparing the duplicate coincidence measurements, a normalization could be made at positions in the gamma spectra which were engendered only by Yb^{169} quanta. A subtraction of the Yb^{169} contributions to the Yb^{175} coincidence spectrum in question could then be made. The measurements were greatly facilitated by the use of the one-hundred channel pulse-height analyzer.

(c) Internal Conversion Electron Measurements

Conversion electron studies were performed with 77 gauss and 141 gauss, 180° permanent magnet spectrographs of high resolution (0.2%). The magnets have pole gap dimensions of 14 in.×20 in.×2 in. into which spectrograph cameras are inserted. The spectrographs are designed so that they can be loaded with film in the daylight without necessitating the removal of the cameras from the magnets. Spectra are recorded on No-Screen X-Ray film. The positions of the lines on the photographic films are measured with a viewer equipped with a vernier caliper. Intensity ratios of L-subshell conversion electrons are inferred from film densitometer measurements with a Leeds and Northrup recording microphotometer. The spectrographs have been calibrated with conversion lines of previously measured gamma transitions from the radioactive decay of Au^{198},[8] Ta^{182},[9] Ir^{192},[8] and Am^{241}.[10]

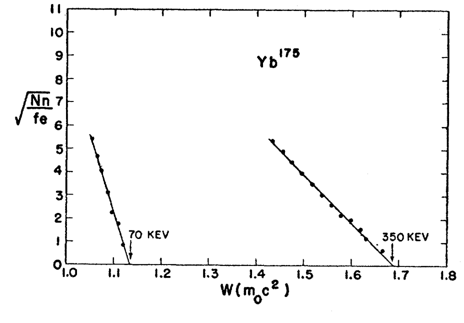

FIG. 4. Fermi-Kurie plot for Yb^{175} obtained from coincidence measurements with the scintillation apparatus.

A series of spectrograms was taken with each source and the relative decay rates of the conversion lines were used to determine whether they originated from Yb^{175} or Yb^{169}. The results of the study showed that (113.6 ±0.2)-, (137.6±0.2)-, (282.4±0.2)-, and (396.0±0.2)-kev transitions accompany the decay of Yb^{175}. Part of the 113.6-kev K-conversion line is attributable to the K-conversion line of a 109.7-kev transition from Yb^{169}. The L-electron spectrum of the 113.6-kev transition consists of $L_{\rm I}$, $L_{\rm II}$, $L_{\rm III}$ lines with intensity ratios of 3, ~1, ~1, respectively.

The relative intensities of the K- and L-conversion lines of the 396.0- and 282.4-kev transitions were measured with a magnetic lens beta-ray spectrometer whose resolution was set for 2.2%. Since the L-conversion electrons from the 282.6-kev transition were not observed, only a lower limit could be set for that particular K/L ratio. The conversion electron data are summarized in Table I.

(d) Beta-Ray Experiments

The beta spectrum of Yb^{175} was examined with the magnetic lens spectrometer. A Fermi-Kurie plot constructed from the data yielded a beta end-point energy of 468±5 kev. No additional beta groups were resolved in the analysis.

The beta spectrum of Yb^{175} was further studied by means of beta-gamma coincidence experiments in which scintillation spectrometers were employed. The beta particles were detected with a bare Pilot Plastic Scintillator-B[11] whereas the gamma rays were detected with a NaI(Tl) crystal. From these experiments it was found that a beta group of end-point energy 350±10 kev is in coincidence with the 113.6-kev transition, and a beta group of end-point energy 70±10 kev is in coincidence with the 396.0- and 282.4-kev transitions. Fermi-Kurie plots of these data are shown in Fig. 4. The end-point regions of these spectra have been corrected for resolution according to the method of Palmer and Laslett.[12]

From the foregoing data it was concluded that the (468±5)-kev beta group is a ground-state transition to Lu^{175}. Therefore, by employing the results of the

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[8] Muller, Hoyt, Klein, and DuMond, Phys. Rev. 88, 775 (1952).

[9] Murray, Boehm, Marmier, and DuMond, Phys. Rev. 97, 1007 (1955).

[10] P. P. Day, Phys. Rev. 97, 689 (1955).

[11] Pilot Chemicals, Inc., 47 Felton Street, Waltham 54, Massachusetts.

[12] J. P. Palmer and L. J. Laslett, Atomic Energy Commission Report AECU-1220, March 14, 1951 (unpublished).

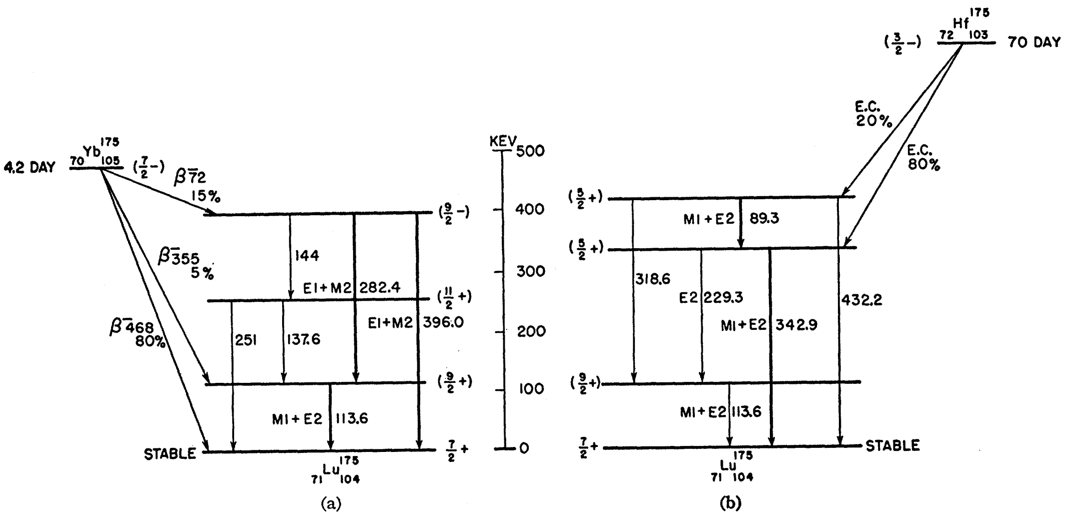

FIG. 5(a) Disintegration scheme of Yb¹⁷⁵, (b) disintegration scheme of Hf¹⁷⁵.

beta-gamma coincidence data and the known energy values of the gamma transitions involved, it is possible to infer that a beta group of end-point energy 355±5 kev populates the 113.6-kev level, and a beta group of end-point energy 72±5 kev populates the 396.0-kev level. By performing additional beta-gamma coincidence experiments, it was concluded that <0.5% of the beta decay takes place to the 251.2-kev level.

A standard beta-gamma coincidence technique was utilized to determine the relative amount of beta branching to the 113.6-kev level and to the ground state. The beta-branching ratio to the 396.0-kev level was determined relative to that to the 113.6-kev level by utilizing the decay fractions given in Table I. The beta-decay data are summarized in Table II and embodied in the decay scheme of Fig. 5(a).

(e) The Internal Conversion Coefficients

The K-conversion coefficient of the 396.0-kev transition was measured by a comparison method. Sources of Yb¹⁷⁵ and Au¹⁹⁸ of comparable surface densities (~1 mg/cm²) were mounted on Scotch tape, and the relative intensities of the 396.0-kev (Yb¹⁷⁵) and 411.8-kev (Au¹⁹⁸) gamma rays were determined with the 2 inch×2 inch NaI(Tl) crystal. The relative intensities of the K-conversion lines of these two gamma rays were then examined in the magnetic lens spectrometer. From these comparison measurements and the theoretical[13] K-conversion coefficient, $\alpha_K = 0.0318$, of the 411.8-kev transition, one can calculate the K-conversion coefficient of the 396.0-kev transition. The value thus obtained is $\alpha_K = 0.050 \pm 0.005$.

The K-conversion coefficient of the 282.4-kev transition was measured by comparing the relative intensities of the 282.4- and 396.0-kev K-conversion electron lines as measured with the magnetic lens spectrometer with their gamma intensities as measured with the 2 inch×2 inch NaI(Tl) calibrated crystal. By combining the results of these measurements and utilizing the experimentally determined K-conversion coefficient for the 396.0-kev transition, a value of $\alpha_K = 0.038 \pm 0.01$ was obtained for the 282.4-kev transition.

In obtaining the multipole assignments of the 396.0- and 282.4-kev transitions, it is to be noted that both transitions involve parity changes. This conclusion is arrived at by observing that both transitions are populated by an allowed beta group and both terminate at levels populated by first forbidden beta groups, see Table II and Fig. 5(a). Thus by comparing the foregoing experimental results for the K-conversion coefficients with theory[13] and utilizing the fact that parity changes are involved in both transitions, it is concluded that the 282.4-kev transition consists of approximately 97 parts $E1$ and 3 parts $M2$, whereas the 396.0-kev transition consists of 83 parts $E1$ and 17 parts $M2$.

To obtain the K-conversion coefficient for the 113.6-kev transition, a coincidence experiment was performed in which the "gate" channel was set to cover the 282.4-kev photopeak, and the coincident 113.6-kev transition and accompanying lutecium K x-ray, engendered by internal conversion of the 113.6-kev gamma, were observed with the 2 inch×2 inch NaI(Tl) calibrated crystal. From the relative intensities of the 113.6-kev gamma and the lutecium K x-ray (x-ray

TABLE II. Beta transitions of Yb¹⁷⁵.

Beta energy (kev)	Percent branch	log ft	Spin and parity
468±5	80	6.4	$\Delta j = 0, 1$, yes
355±5	5±2	7.3	$\Delta j = 0, 1$, yes
72±5	15±5	4.7	$\Delta j = 0, 1$, no

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[13] Rose, Goertzel, Harr, Spinrad, and Strong, Phys. Rev. **83**, 79 (1951).

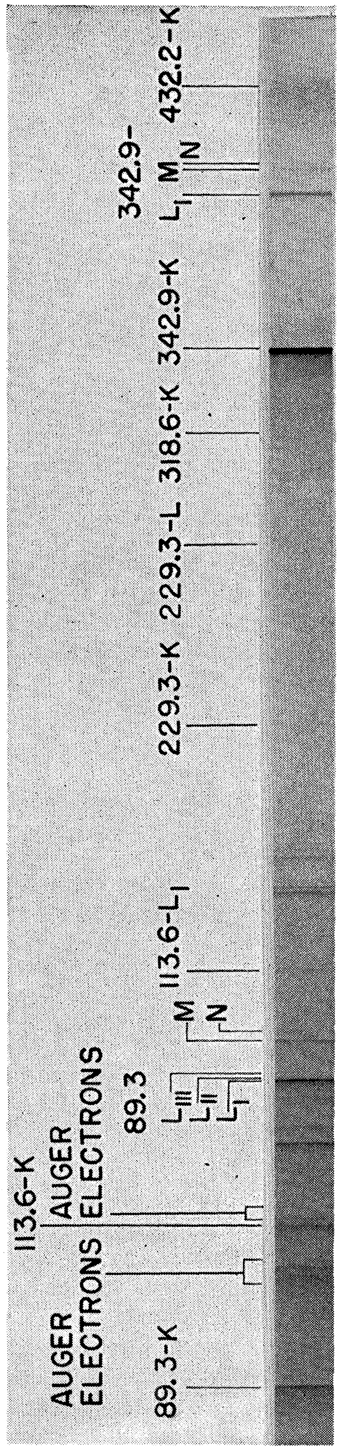

FIG. 6. Hf^{175} conversion electron spectrum taken with the 141 gauss permanent magnet spectrograph. The unlabeled lines are associated with Hf^{181} decay.

intensity corrected for fluorescence yield[14]), a value of $\alpha_K = 1.7 \pm 0.4$ was obtained. Combining this K-conversion coefficient with the L-subshell conversion ratios (Table I), we conclude that the 113.6-kev radiation consists of three parts $M1$ and one part $E2$.[13,15]

III. Yb^{175} DECAY SCHEME

The Yb^{175} decay scheme shown in Fig. 5(a) has been constructed on the basis of the data summarized in Tables I and II. A brief account of the arguments involved in the construction of the level scheme follows.

The measured spin of 7/2 infers a shell model assignment[16] of $g_{7/2}$ for the ground state of Lu^{175}. From experimental evidence to be presented below we have assigned spin and parity values of 9/2+ and 11/2+ to the 113.6- and 251.2-kev levels, respectively, in accordance with the spin sequence I_0, I_0+1, I_0+2, (all parities the same as the ground state) as demanded by collective motion in highly deformed nuclei for members of a rotational band.[2] Interpretation of the levels at 113.6-kev (E_{I_0+1}) and 251.2 kev (E_{I_0+2}) as members of a rotational band with the base state E_{I_0} formed at stable Lu^{175}(7/2+) is supported, in part, by the fact that the experimental ratio E_{I_0+2} to E_{I_0+1} is 2.211 ± 0.005 whereas the theoretical ratio[2] is 2.222. The deviation from the theoretically expected ratio lies in the direction and is of the proper order of magnitude to be expected from vibration-rotation interaction effects.[2] It is to be noted that the $M1+E2$ character of the 113.6-kev transition is in agreement with what one would expect from the assigned spin and parity values of the base state and first rotational level. The enhancement of the $E2$ radiation ($E2/M1 \sim 30\%$) for the 113.6-kev transition is, as Bohr and Mottelson have pointed out, a direct consequence of the large nuclear deformations known to exist in the rare-earth region of the periodic table. It is also to be noted that the Yb^{175} beta-decay data infer that the parities of the ground state and first excited state (113.6 kev) are the same. Finally, the 113.6- and 251.2-kev levels are undoubtedly identical with the 114- and 250-kev levels reported by Heydenburg and Temmer in the Coulomb excitation of Lu^{175}.[3] Thus, there seems to be no experimental evidence in the Yb^{175} decay scheme to contradict the assignment of spins and parities to the levels in the observed rotational band of Lu^{175} as predicted by the Bohr-Mottelson theory. Additional evidence to be presented below on the decay of Hf^{175} will further strengthen the assignments.

Several experimental facts must be considered simultaneously in order to arrive at satisfactory spin and parity values for the 396.0-kev level. It has been previously shown (Sec. IIe) that $E1+M2$ transitions from this state decay to the 7/2+ and 9/2+ levels [Fig. 5(a)]. Since it was observed in the coincidence studies that the 137.6- and 144-kev transitions are of comparable intensities, it can be inferred from the relative intensities of the conversion electrons of the 137.6- and 144-kev transitions that the 144-kev transition is probably $E1$ or $E2$. The $E2$ possibility is eliminated by the parity change involved and hence an $E1$ transition from the 396.0-kev level is thought to populate the 11/2+ level. Thus the most reasonable assignment for the 396.0-kev level is 9/2−.

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[14] Broyles, Thomas, and Haynes, Phys. Rev. **89**, 715 (1953).

[15] Rose, Goertzel, and Swift (private circulated tables).

[16] P. F. A. Klinkenberg, Revs. Modern Phys. **24**, 63 (1952).

With the assignment of spin and parity values to the observed levels in Lu^{175} completed, it is now possible from the beta-decay data of Table II to arrive at an assignment of 7/2− for the ground state of Yb^{175}. This assignment is identified with an $f_{7/2}$ single particle level although the $f_{7/2}$ subshell is normally filled for odd-neutron nuclei with neutron number greater than 101.[16]

IV. DECAY OF Hf^{175}

(a) Internal Conversion Electron Measurements

Hf^{175} was prepared by thermal neutron bombardment of HfO_2 electromagnetically enriched in Hf^{174} (10.2%).[17] The initial studies were carried out with the 77 gauss and 141 gauss, 180° permanent magnet spectrographs. Figure 6 shows the conversion electron lines associated with the Hf^{175} decay. These lines correspond to gamma-ray transitions of the following energies: 89.3 ± 0.2, 113.6 ± 0.2, 229.3 ± 0.2, 318.6 ± 0.2, 342.9 ± 0.2 and 432.2 ± 0.2 kev (see Table III). The transitions fit nicely into a previously proposed decay scheme.[18,19]

The L-subshell conversion ratios (Fig. 6) proved to be extremely helpful in the assignment of multipolarities to the various gamma rays involved in the Hf^{175} decay. The 89.3-kev transition has L-subshell conversion ratios of 10:1:1. From theoretical L-subshell conversion coefficients[15] it is possible to deduce that the transition consists of approximately 10 parts $M1$ and 1 part $E2$. The 342.9-kev transition exhibits no observable conversion in the L_{II} and L_{III} subshells. This fact coupled with the experimentally determined $K/(L+M)$ ratio of 5.0 ± 0.5 demonstrates that the transition is an $M1+E2$ admixture with $E2/M1\leqslant0.25$. The 113.6-kev transition is considered to be identical with the one found in the decay of Yb^{175}. Its weak intensity as observed in the Hf^{175} decay precludes a study of its L-subshell conversion ratios other than to observe that it is mainly converted in the L_{I} shell which is indicative of its predominant $M1$ character. Because of the low intensity of the 229.3-kev transition, a satisfactory study of its L-subshell conversion ratios could not be performed. However, by comparing the intensities of its weak K and L lines on the spectrogram, a crude estimate of the K- to L-conversion ratio ($K/L\sim2$) could be made.

The relatively poor resolution (2.2%) of the magnetic lens spectrometer precluded an investigation of the K/L ratios for the extremely weak 113.6-, 229.3-, 318.6- and 432.2-kev transitions. A K/L ratio of 5.0 ± 0.5 was, as previously mentioned, obtained for the 342.9-kev transition. The lack of agreement of reported K/L ratios[18,19] for the 89.3-kev transition is undoubtedly attributable, in part, to source thickness effects. The relative L-subshell conversion coefficients as measured herein, however, should be quite definitive for making the $M1+E2$ assignment to the 89.3-kev transition.

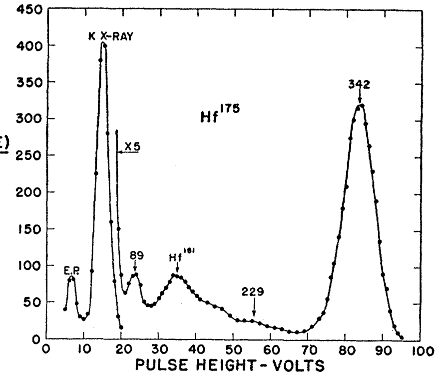

FIG. 7. Gamma-ray spectrum of Hf^{175} obtained with a 1½ inch ×1½ inch NaI(Tl) crystal. The high-energy region is shown on an enlarged scale (×5).

(b) Gamma-Ray Measurements

Additional information concerning the radiations of Hf^{175} was obtained from measurements with the scintillation apparatus. A survey of the photon spectrum revealed the presence of lutecium K x-rays and 89-, 229-, and 342-kev gamma rays (see Fig. 7). The photopeak (A) of Fig. 7 is engendered by 131- and 135-kev gamma rays[4] which accompany Hf^{181} decay. Absence of annihilation radiation indicated that Hf^{175} decays entirely by orbital electron capture.

The photon spectrum was further studied with the calibrated 2 inch×2 inch NaI(Tl) crystal. With the source to detector geometry arranged to avoid "pile-up" of coincident gamma rays, the relative gamma intensities of the 229-, 342-, and 432-kev transitions were determined. The gamma intensity data are summarized in Table III.

Several gamma-gamma coincidence experiments were performed on the gamma rays accompanying the Hf^{175} decay. Coincidences were observed between the 89-kev and 342-kev transitions. Because of the low intensities of the 318- and 114-kev transitions relative to those of the 89- and 342-kev transitions, it proved impossible to do definitive coincidence experiments on the 318-kec to 114-kev cascade and the 229-kev to 114-kev cascade. It is felt, however, that the energy values

TABLE III. Gamma transitions of Hf^{175}.

Gamma energy (kev)	Relative gamma intensities	Relative transition intensities	$L_{\text{I}}:L_{\text{II}}:L_{\text{III}}$	$K/(L+M)$	Multipolarity
89.3	3.7 ± 1	22 ± 6	10:1:1	···	$E2/M1\sim0.1$
113.6	···	3.0 ± 1	···	···	$M1+E2$
229.3	1 ± 0.5	1.2 ± 0.5	···	$K/L\sim2$	$E2$
318.6	···	1.5 ± 0.5	···	···	$(E2)^{a}$
342.9	100 ± 10	110 ± 10	10:−:−	5.0 ± 0.5	$E2/M1\leq0.25$
432.2	2 ± 1	2 ± 1	···	···	$(M1)^{a}$

[a] Multipolarity assignment deduced from decay scheme of Fig. 5(b).

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[17] The samples of hafnium, enriched in Hf^{174}, were obtained on loan from the Isotope Research and Production Division of the Oak Ridge National Laboratory, Oak Ridge, Tennessee.

[18] S. B. Burson and W. C. Rutledge, Phys. Rev. **86**, 633(A) (1952).

[19] Burford, Perkins, and Haynes, Phys. Rev. **95**, 303(A) (1954). *Note added in proof.*—See also Burford, Perkins, and Haynes, Phys. Rev. **99**, 3 (1955).

determined by the magnetic spectrograph measurements are sufficiently conclusive to establish these genetic relationships.

V. Hf^{175} DECAY SCHEME

The data given in Table III establish most of the features of the decay scheme shown in Fig. 5(b). From the relative transition intensity data given in Table III, it appears that little, if any, orbital electron capture takes place to the 113.6-kev level. To determine the K-capture ratios to the 342.9- and 432.2-kev levels a coincidence experiment was performed with the scintillation apparatus. With the "gate" channel set to cover the 342-kev photopeak, the coincidence spectrum of the 89-kev gamma ray and lutecium K x-rays was examined. The K x-rays are engendered partly by K-capture transitions to the 342.9-kev and 432.2-kev levels and partly by K-conversion of the 89-kev transition. From the measurement of the relative intensities of the 89-kev gamma and lutecium K x-ray and by utilizing the K-fluorescence yield,[14] the estimated L- to K-capture ratio of 17%,[20] and the estimated K-conversion coefficient and K/L ratio for the 89.3-kev transition,[13,15] K-capture branching ratios of ~80% to the 342.9-kev level and ~20% to the 432.2-kev level were obtained. Further studies of the "ungated" gamma-ray spectrum with the calibrated 2 inch×2 inch NaI(Tl) crystal indicated from the lutecium K x-ray intensity relative to that of the 342-kev gamma intensity that little, if any (<10%), orbital electron capture takes place to the ground state of Lu^{175}.

By observing [Fig. 5(b)] that the 342.9-kev level decays by $M1+E2$ radiation to the 7/2+ ground state, a spin and parity assignment of 5/2+, 7/2+, or 9/2+ can be made for the 342.9-kev level. A 5/2+ assignment for the 342.9-kev level would seem to be the most probable in view of the absence of observable K-capture to the 7/2+ ground state and to the 9/2+ excited state at 113.6 kev. From the $M1+E2$ character of the 89.3-kev transition, a tentative assignment of 5/2+ is made for the 432.2-kev level. Perhaps one of the foregoing 5/2+ levels is to be identified with a $d_{5/2}$ level available from shell theory.[16] It is to be noted that the remaining 5/2+ level excited by Hf^{175} decay and the 9/2− level excited by Yb^{175} decay are not readily explainable on the basis of the shell model.

By utilizing the beta-energy systematics of Way and Wood[21] (which give a disintegration energy of ~900 kev) and the above K-capture branching ratios, log ft values of 7.8 and 7.4 are determined for the 20% and 80% K-capture branches, respectively. This suggests that a spin change of one unit and a parity change are realized in both K-capture transitions. Since there is no observable K-capture to the 7/2+ Lu^{175} ground state (log $ft>8.8$), a spin and parity assignment of 3/2− is therefore made for the ground state of Hf^{175}. This ground-state assignment is probably to be identified with a $p_{3/2}$ configuration which is available from shell theory.[16]

VI. ACKNOWLEDGMENTS

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Note added in proof.—A detailed discussion of the nuclear levels and transitions in Lu^{175}, according to the unified model, by L. Wilets and D. M. Chase of the Los Alamos Scientific Laboratory, has been submitted for publication [Phys. Rev. (to be published)].

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[20] M. E. Rose and J. L. Jackson, Phys. Rev. **76**, 1540 (1949).

[21] K. Way and M. Wood, Phys. Rev. **94**, 119 (1953).

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Spectrometry of the Neutrino Recoils of Argon-37

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The ions that recoil from neutrino emission in the electron capture decay of A^{37} have been subjected to magnetic spectrometry with a resolution amounting to 2.8% in energy. They are found to have an energy of 9.63 ± 0.06 ev, which is in agreement with the value 9.65 ± 0.05 ev to be expected on the basis of a two-body breakup, the neutrino having an energy of 815 ± 2 kev as determined by others from the threshold of the $Cl^{37}(p,n)A^{37}$ reaction. The momentum balance sets an upper limit of about 5 kev for the rest mass of the neutrino. Auger electron emission following the orbital electron capture leaves the recoils mostly multiply charged, the percentage abundances in charge states 1 to 7 being 6.2 ± 0.1, 15.7 ± 0.4, 39.2 ± 0.5, 26.7 ± 0.4, 10.0 ± 0.2, 1.8 ± 0.1 and 0.4 ± 0.1, respectively. Neutrals were not measured. The natural width at half-intensity of the singly-charged recoil line is 1.7 ev, which is fully accounted for by the thermal motion of the argon atoms. The natural width of the triply-charged recoil line is 2.5 ev, which is mostly but not entirely accounted for by thermal motion plus recoil from the emission of one 2300-ev K Auger electron. The singly-charged recoils are thought to result from L-capture and from K-capture followed by K x-ray emission, neither of these processes involving recoil from the 2300-ev Auger electron.

ARGON-37 is an attractive substance for neutrino recoil experimentation because it possesses a number of simultaneously favorable properties. It is an electron-capturing radionuclide with a half-life of 34 days, and its decay is unaccompanied by gamma emission, so the predominant mechanism giving recoil should

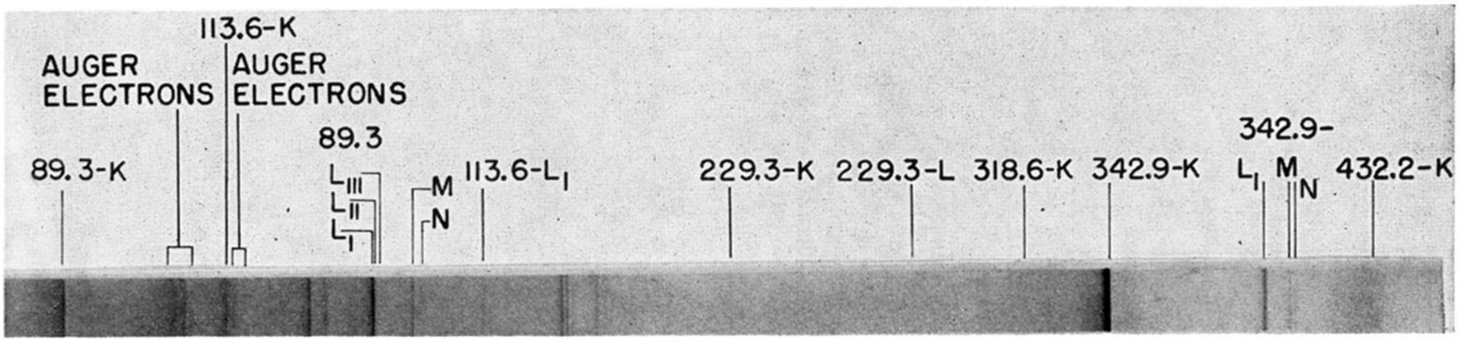

FIG. 6. Hf^{175} conversion electron spectrum taken with the 141 gauss permanent magnet spectrograph. The unlabeled lines are associated with Hf^{181} decay.