Unique first forbidden beta decay of ^{183}Re and ^{185}Os†

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The decays of ^{183}Re and ^{185}Os were studied by γ-ray spectroscopy using Ge(Li) detectors. The $\log f_1 t$ value for the 5/2 5/2$^+$[402]→9/2 1/2$^-$[510] transition between ^{183}Re and ^{183}W was 9.3, which contrasts to the previously reported value of 8.0. The 5/2 1/2$^+$[402] K-2 γ-vibrational state of ^{185}Re was identified for the first time at 768.93 keV. This level is populated from the 1/2 1/2$^-$[510] ground state of ^{185}Os with a $\log f_1 t$ value of 10.4.

[RADIOACTIVITY ^{183}Re [from ^{182}W(α, 3n), $W(\alpha, xn)$ (9.9-h, 14-h, EC) ^{183}Re]; ^{185}Os [from $W(\alpha, xn)$]; measured $E\gamma$, $I\gamma$, $T_{1/2}$, deduced logft, ^{183}W, ^{185}Re deduced levels, J, π. Ge(Li) detectors; enriched, natural targets.]

I. INTRODUCTION

The unique first forbidden (U1F) β decay of nuclei is of particular interest, because it is governed by the single matrix element $\langle \sigma \cdot \tau_2^1 \rangle$. In light nuclei, the strength of U1F decays is approximately 10^{-2} of theoretical strength.[1] Few cases have been measured with sufficient precision to determine a general trend in heavier nuclei. Here we report our results on two deformed nuclides which have been reported to have surprisingly fast U1F transitions.[2,3]

Recently, Ellis[2] reviewed the experimental literature for A = 185. In this review the available data for the decay of 94-day ^{185}Os were used to propose levels in ^{185}Re which had properties inconsistent with those known for the same states in ^{187}Re.[4] For example, the proposed $\frac{5}{2}^+$ member of the K-2 γ vibration built on the $\frac{5}{2}^+$[402] ground state of ^{185}Re was placed at 767.3 keV. The level was assumed to deexcite solely to the γ vibration bandhead at 646.1 keV rather than predominantly to the ground state as would be expected for a γ-vibrational state. The latter expected pattern has been observed in the decay of the neighboring isotope ^{187}W which populates levels in ^{187}Re.[4] Also, the deduced $\log f_1 t$ value (9.16) for the unique first forbidden β decay to the 767.3-keV level seems too low; the rate is at least an order of magnitude too fast for this type of transition.[1]

The present study of the ^{185}Os decay was initiated to resolve these and other problems in the scheme. Previous attempts to study this decay have been hampered by the difficulty of isolating highly pure Os sources. We have developed and report here a new technique for isolating pure Os activity from W targets.

The recent compilation for A = 183 by Artna-Cohen[3] points to a number of difficulties in the published data on ^{183}Re decay. The γ ray intensities lead to negative electron capture (EC) feeding of some levels, and several transitions suggest improbable feeding of levels which are known from other experiments. Most interesting is the EC feeding of the $\frac{9}{2}^-$ member of the $\frac{1}{2}^-$[510] ground-state band at 308.9 keV with a reported $\log f_1 t$ value of 8.0. This value, if true, would represent one of the fastest unique first forbidden transitions known (see, for example, the compilations by Raman and Gove[5]). In the deformed region, the strength of the $\langle \sigma \cdot \tau_2^1 \rangle$ matrix element, hence $\log f_1 t$ values, is known with precision in only a few cases. Therefore, we reinvestigated ^{183}Re decay with the aim of resolving discrepancies, thereby providing a better measure of the U1F β decay to the $\frac{1}{2}^-$[510] band.

II. EXPERIMENTAL METHODS AND RESULTS

A. Sources of ^{185}Os

We could find in the literature no satisfactory technique for separation of Os from W metal. Consequently, we developed a technique that produces pure Re-free Os sources. Because our measurements and their interpretation depend on the high purity of the sample, a detailed description of our chemical procedure is included below.

Sources of pure ^{185}Os were prepared by irradiating a 0.25 mm tungsten foil with α particles using the 223-cm cyclotron at the Lawrence Berkeley Laboratory. After a waiting period of approximately six months, the foil was placed in an all-

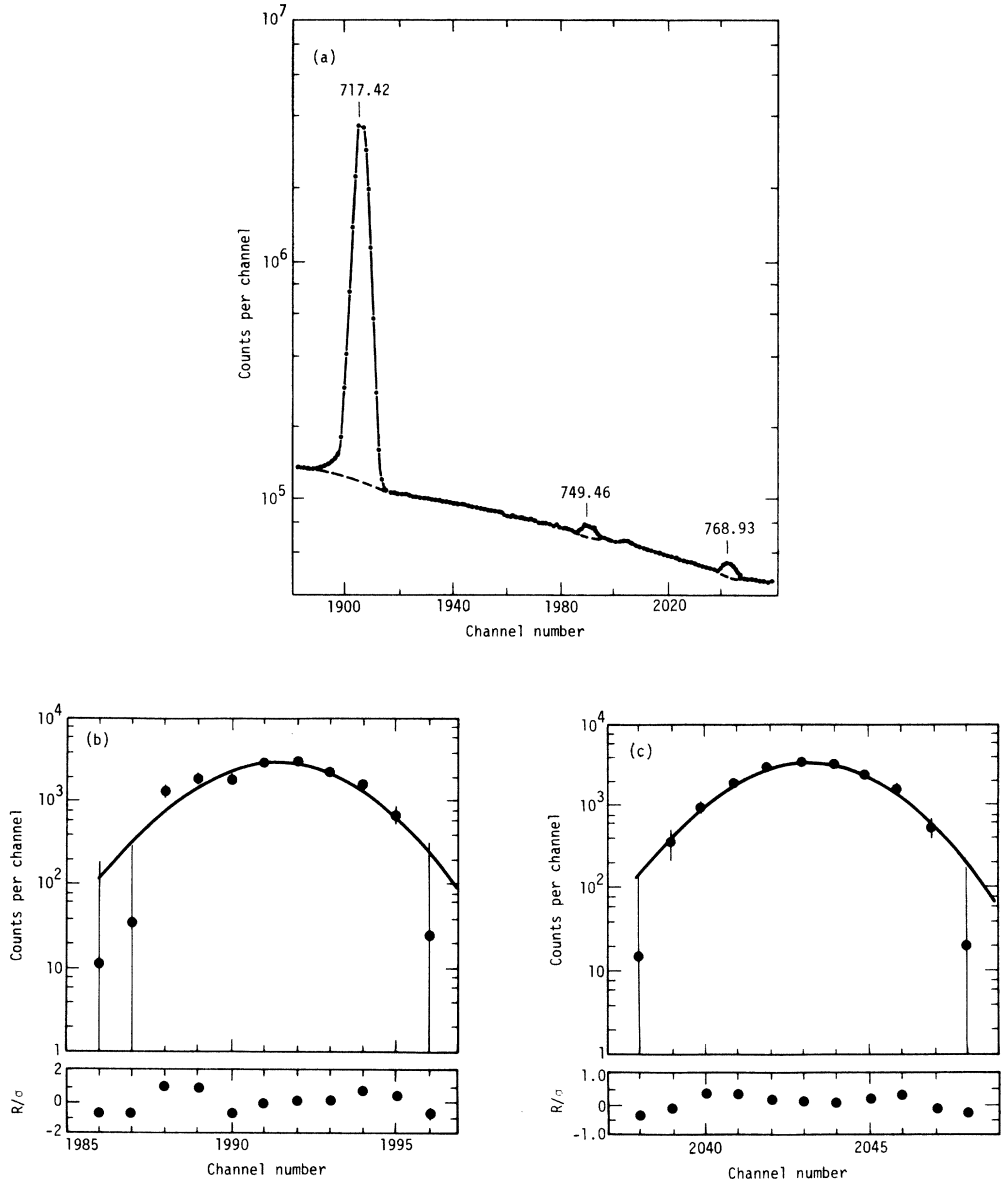

FIG. 1. The γ-ray spectrum of ^{185}Os decay taken with 10 mm of Pb as an absorber between the source and detector: (a) region from 700 to 800 keV, (b) fit of GAMANAL peak shape (less background) to the 749.46-keV photopeak, and (c) fit of GAMANAL peak shape (less background) to the 768.93-keV photopeak.

glass distillation flask fitted with an input air stream, a water-cooled condenser, and an enclosed catcher tube. The catcher tube contained an equal-volume mixture of ethyl alcohol and concentrated hydrochloric acid. Several grams of solid sodium nitrite were added to the distillation flask containing the tungsten, and a small flow of air was started (approximately one bubble/sec passed through the alcohol-HCl catcher solution). The distillation flask was then rapidly heated until the solid salt melted, and a vigorous reaction occurred between the melt and the tungsten foil. At this stage, any osmium tetroxide which may have formed was swept out of the flask and into the catcher solution. The flask contents were cooled, and the air flow was disconnected from the glass input tube. A few milliliters of 1*N* sulfuric acid were added through the input tube, the air supply was reconnected, and the flask contents were warmed until the solid material dissolved in the acid. After again disconnecting the air flow, a fresh solution of potassium bromate was added

TABLE I. The γ rays assigned to ^{185}Os decay.

E_γ (ΔE_γ) (keV)	I_γ (ΔI_γ) [a]	Assignments From	To
71.313(2)	31(16) [b]	717	646
121.2(1)	c	...	...
125.358(3)	43.1(4)	125	0
162.852(7)	69.3(7)	880	717
234.157(9)	51.4(7)	880	646
592.066(10)	164(1)	717	125
646.116(9)	10 000 [d]	646	0
717.424(12)	509(2)	717	0
749.456(73)	0.40(5)	874	125
768.929(53)	0.45(4)	768	0
805.699	0.005(4) [e]	931	125
874.813(13)	816(4)	874	0
880.523(13)	617(3)	880	0
931.057(15)	6.1(2)	931	0

[a] Normalized to 10 000 at 646 keV.

[b] This γ ray was not resolvable from x rays in our singles spectra. Intensity value is taken from Ref. 8.

[c] No γ rays were observed in this energy region of the spectra. However, when the source to detector distance was small, x-ray sum peaks of 120 and 121 keV were observed.

[d] Fiducial γ-ray peak shape was fit to 0.3%.

[e] An 808-keV sum peak was observed to mask this peak in some spectra.

through the input tube. The air flow was reconnected, and the solution was cautiously heated to and maintained at boiling until roughly half the water had distilled into the catcher. Usually 90% or more of the osmium tetroxide distilled into the catcher on the first bromate treatment. A second treatment was generally successful in removing most of the osmium remaining in the distillation flask.

Because the initial reaction between the tungsten metal and sodium nitrite was extremely vigorous and liberated considerable heat, small quantities of ^{183}Re and ^{184}Re (as the slightly volatile Re_2O_7) were carried over into the alcohol-HCl catcher solution. For this reason, the latter solution was transferred to a flask, boiled to a small volume, and transferred to a new distillation flask. The osmium was distilled from this solution, as described above, by acidification with potassium bromate. The distillate showed no evidence for the presence of either ^{183}Re or ^{184}Re. A very low level of these nuclides could be detected, however, in the residue of the second distillation flask.

The alcohol catcher solution containing the second osmium distillate was reduced short of dryness, by boiling and evaporation, to a volume sufficiently small to serve as a satisfactory γ-ray source. A "massless" source was prepared from a part of this solution via electroplating.

The sources were counted using a low energy photon spectrometer (LEPS) and large volume Ge(Li) spectrometers. Separate measurements were made using up to 10 mm of Pb absorber to

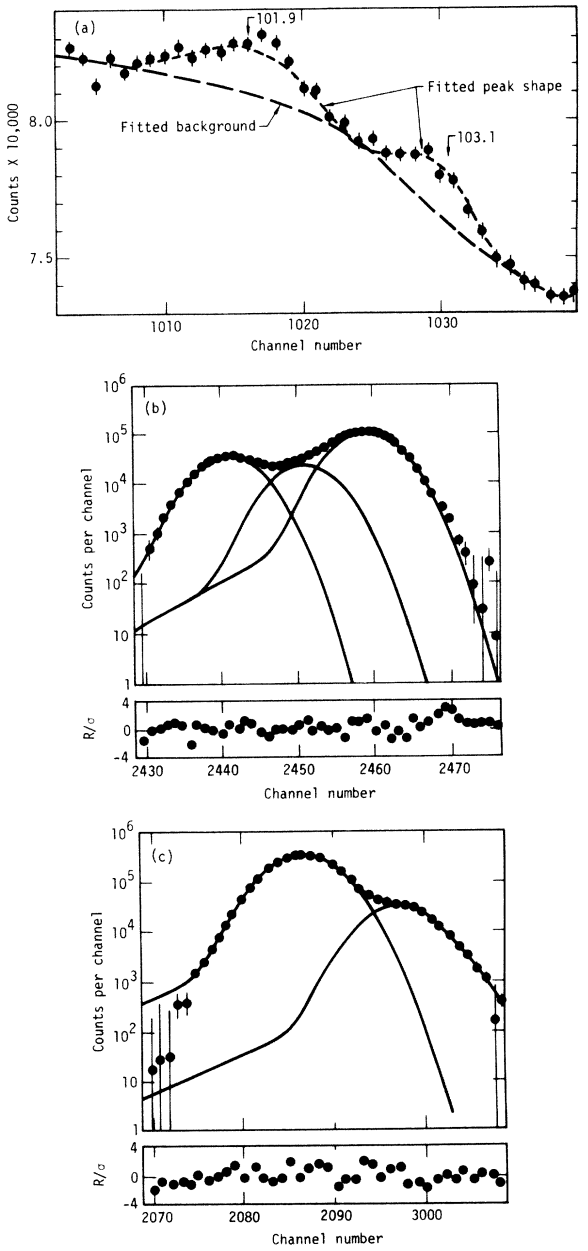

FIG. 2. Selected photopeaks in the spectra of ^{183}Re decay: (a) region showing the 101.9- and 103.1-keV photopeaks, (b) fit of GAMANAL peak shape to the 244.27-, 245.25-, and 248.06-keV triplet, (c) fit of GAMANAL peak shape to the 208.81- and 209.89-keV doublet. For the fit in (b) and in (c), parameters for peak shape were determined from several single photopeaks within the same spectrum.

TABLE II. The γ rays assigned to ^{183}Re decay.

E_γ (ΔE_γ) [a] (keV)	I_γ (ΔI_γ) [b]	Assignments From	To
40.976(1)	8(2)	453	412
46.484(1)	2516(17)	46	0
52.596(1)	699(21)	99	46
82.919(2)	80(1)	291	208
84.712(2)	275(6)	291	207
99.080(2)	850(17)	99	0
101.933(37)	5.5(5)	308	207
102.481(–)	c	(309	207)
103.100(100)	1.2(5)	412	308
107.933(2)	687(14)	207	99
109.731(2)	915(20)	208	99
120.372(90)	0.98(17)	412	291
143.589(–) [d]	e	(453	309)
144.135(4)	36.6(7)	453	308
160.532(4)	186(2)	207	46
161.342(14)	114(15)	453	291
162.330(5)	7373(37)	208	46
192.646(7)	81(2)	291	99
203.269(12)	14.4(8)	412	208
205.081(9)	35(1)	412	207
208.812(2)	939(4)	208	0
209.890(7)	83(2)	308	99
210.300(–)	f	(309	99)
244.266(3)	130(3)	453	208
245.243(6)	81(12)	291	46
246.062(2)	417(12)	453	207
291.723(7)	1000(3)	291	0
313.021(5)	131(3)	412	99
353.998(5)	169(3)	453	99
365.614(9)	21.3(9)	412	46
406.593(16)	7.9(5)	453	46

[a] E_γ calibrated using standard values from Refs. 10 and 11 for ^{113}Sn, ^{133}Ba, ^{182}Ta, and ^{183}Ta.
[b] Normalized to 1000 at 291 keV.
[c] No γ ray observed. Intensity limit is < 0.5 units.
[d] E_γ taken from ^{183}Ta decay.
[e] No γ ray observed. Intensity limit is < 0.7 units.
[f] No γ ray observed. Intensity limit is < 2 units.

eliminate summing from x rays and lower-energy γ rays and to suppress low-energy portions of the spectrum relative to the high-energy γ rays. The ^{185}Os sources were counted simultaneously with standard sources[6] to permit accurate energy calibration. All spectra were analyzed with the code GAMANAL[7] on CDC 7600 computers. Illustrative portions of the spectrum in the 700- to 800-keV region are shown in Fig. 1. Detailed results of the γ-ray energies and intensities are presented in Table I.

B. ^{183}Re

The ^{183}Re sources were prepared by two methods. In one, high purity ^{183}Re was obtained by first producing ^{183}Os via the ^{182}W(α, 3n)^{183}Os reaction on enriched targets followed by a chemical separation of Os. These sources were essentially pure ^{183}Os. After a two-month delay to allow for growth of the daughter activity, measurements were undertaken on ^{183}Re decay. Additional sources were produced by the W(α, xn)^{183}Os reaction on natural-abundance W foils. These sources contained approximately equal parts of ^{183}Re and ^{185}Os, after allowing for decay of the ^{183}Os, and were used for energy and cross-calibration purposes.

The γ-ray measurements were made using LEPS and large volume Ge(Li) spectrometers. In addition, spectra were measured using an intrinsic-Ge, Compton suppression spectrometer with a suppressor ratio of 600 to 1. Sources were counted simultaneously with known standards[6] and all spectra were analyzed on CDC 7600 computers using the code GAMANAL. Figure 2 shows selected portions of spectra that illustrate the separation or detection of critical photopeaks. γ-ray energies and intensities are listed in Table II.

III. DECAY SCHEMES AND DISCUSSION

A. ^{185}Os

The decay scheme for ^{185}Os is shown in Fig. 3. To calculate the absolute EC intensities, we per-

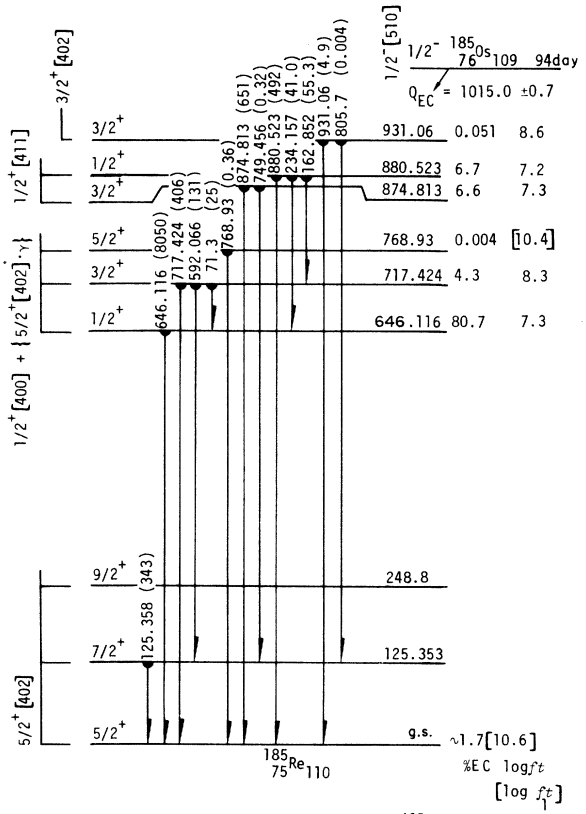

FIG. 3. Decay scheme for ^{185}Os.

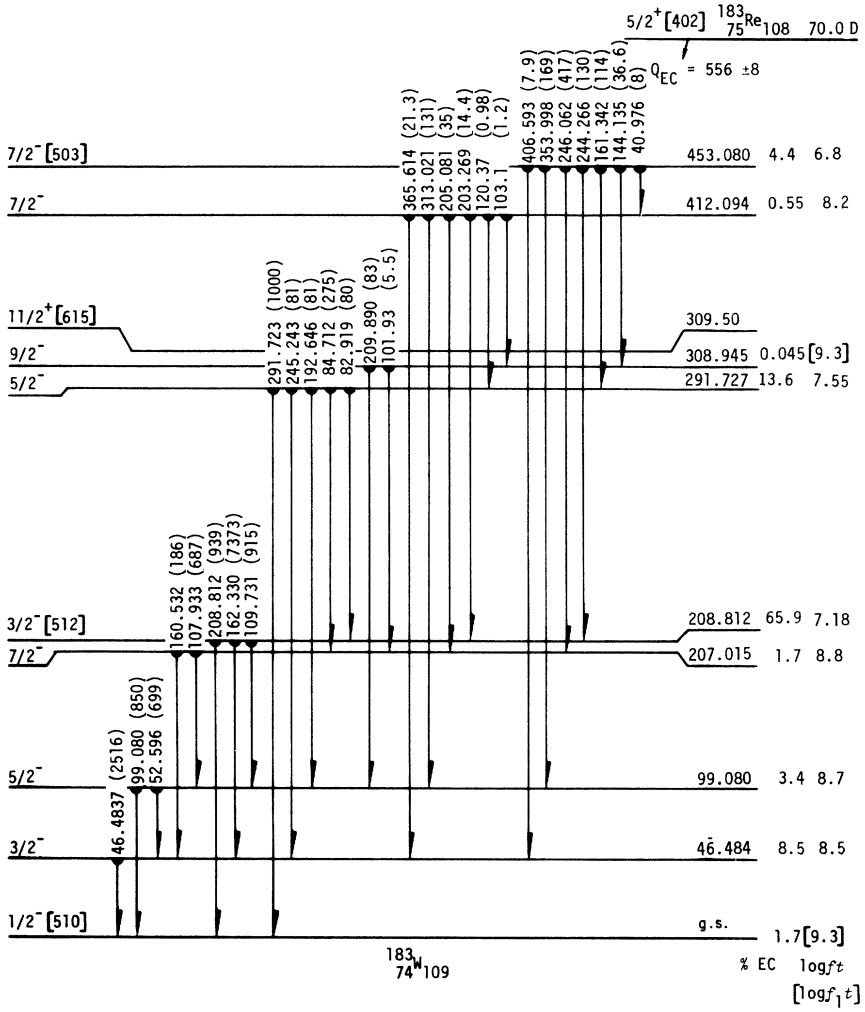

FIG. 4. Decay scheme for ^{183}Re. (The $\frac{11}{2}^+$ [615] band head at 309.50 keV is *not populated* in this decay. We include the known 5.15-s, $\frac{11}{2}^+$ isomer for purposes of comparison with previous studies (see text).)

formed a detailed intensity balance for each level. We calculated the ground-state EC feeding by using our K x-ray intensities, a fluorescence yield (ω_K) of 0.951 for $Z = 75$ as given by Fink *et al.*,[11] the K-conversion electron intensities, and a total electron-capture to K-capture intensity ratio of 1.191 as given by Lederer, Hollander, and Perlman.[12] We calculate a value of (1.7 ± 0.9)% for EC feeding to the ground state.

We suggest that the $\frac{5}{2}^+$ member of the K-2 γ vibration built on the $\frac{5}{2}^+$[402] ground-state band of ^{185}Re occurs at 768.93 keV. The logf_1t value of 10.4 is consistent with values found for other U1F decays in this mass region [e.g., ^{187}W(9.5, 10.4, 11.4) and ^{177}Ta(10.7)]. Earlier work[2] placed the $\frac{5}{2}^+$ member at 767.3 keV and suggested that the level was depopulated by a 121.2-keV transition. In some spectra, we observed a peak at 121.2 keV which was shown to result from x-ray summing. Presumably, this is what Bedike *et al.*[13] observed in their work. The transition to the ground state that we observe is the expected decay mode for this type of level and is known to occur in the neighboring isotope ^{187}Re.[4] Deexcitation to the $\frac{7}{2}^+$ member of the ground-state band would be by a 643.57-keV γ ray which would be masked in our spectra by the strong 646.12-keV photopeak.

We have discussed elsewhere[4] the $\frac{1}{2}^+$[411] bands, their apparent variable decoupling, and the influence of Coriolis mixing of the $\frac{1}{2}^+$[411] and $\frac{3}{2}^+$[402] bands. The $E2$ decay of the $\frac{3}{2}^+$ member of the $\frac{1}{2}^+$[411] band located at 874.81 keV in ^{185}Re to the 125.36-keV, $\frac{5}{2}\frac{7}{2}^+$[402] level would be expected to be weak. Our branching ratio of 5×10^{-4} for the 749.45-keV γ ray suggests that the $E2$ decay of this level in ^{185}Re is approximately five times slower

than in ^{187}Re.[4] This low value contrasts to that of Bedike *et al.*,[13] who reported an intensity about 13 times larger. Presumably their value is in error as a result of normalization procedures, because they were only able to identify the 749-keV γ ray by performing coincidence measurements.

The $\frac{3}{2}^+[402]$ level occurs at 931.06 keV in ^{185}Re while this level is at 772.87 keV in ^{187}Re. Several attempts have been made to measure the branching of this level via a 805.70-keV transition to the $\frac{7}{2}^+$ member of the $\frac{5}{2}^+[402]$ ground-state band. Our value of 8.2×10^{-4} for this branch in ^{185}Re is in agreement with our earlier work[4] on ^{187}Re, where a value of 7.8×10^{-4} was measured. In previous studies on ^{187}Re, this ratio was set too high by a factor of 10. In general and contrary to earlier studies, the properties of levels in ^{185}Re that we observe are consistent with the detailed properties of ^{187}Re.

B. ^{183}Re

We present the ^{183}Re decay scheme in Fig. 4. Our energy values compare well with those determined by other techniques.[3] The logft values were calculated using the tables of Gove and Martin[14] together with our absolute intensity values. The latter were calculated in the manner described for the ^{185}Os decay, using an ω_K of 0.945, and an EC (total) to EC(K) ratio of 1.189. We obtain a (1.7 ±0.6)% ground-state EC branch. We have not detected any γ rays associated with the decay of the known 5.15-s, $\frac{11}{2}^+$ isomer at 309.49 keV. Our intensity limits are such that we can require any detectable conversion-electron intensity to be a factor of 10 less than previously reported.[3]

We obtain a logf_1t value of 9.3 ±0.2 for the unique first forbidden β decay of the $\frac{5}{2}^+[402]$ ^{183}Re ground state to the $\frac{9}{2}^-$ member of the $\frac{1}{2}^-[510]$ ground-state band in ^{183}W. The uncertainty in the logf_1t value arises from the uncertainty in the Q_{EC} value of 556 ±8 keV and the conversion coefficients of the transitions that populate and depopulate the 308.94-keV level. This value, although low, is now consistent with the rules of Raman and Gove.[5]

IV. SUMMARY

We have shown that the U1F β decay of two deformed nuclides, ^{183}Re and ^{185}Os, have logf_1t values within the average range expected. More detailed analysis of the $\langle\sigma\cdot\tau\frac{1}{2}\rangle$ strength in the deformed region must await a larger body of information for this class of β decay. The $\frac{5}{2}^+$ member of the K-2 γ vibration built on the $\frac{5}{2}^+[402]$ ground state of ^{185}Re has been located at 768.93 keV.

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