Title

ISOMERS IN 156Gd, 172Yb, AND 182W

Permalink

https://escholarship.org/uc/item/93j8z8rr

Authors

Nordhagen, R.
Diamond, R.M.
Stephens, F.S.

Publication Date

1969-08-01

Submitted to Nuclear Physics

UCRL-18965
Preprint

ISOMERS IN ^{156}Gd, ^{172}Yb, AND ^{182}W

R. Nordhagen, R. M. Diamond, and F. S. Stephens

August 1969

AEC Contract No. W-7405-eng-48

LAWRENCE RADIATION LABORATORY
UNIVERSITY of CALIFORNIA BERKELEY

KEY WORDS

NUCLEAR REACTIONS: Sm, Er, Hf (α,2n), E_{α} = 27 MeV, measured $t_{1/2}$, E_{γ}, I_{γ}, I_{ce}, ^{156m}Gd, ^{172m}Yb, ^{182m}W deduced decay scheme, natural and separated targets.

ISOMERS IN ^{156}Gd, ^{172}Yb, AND ^{182}W[†]

R. Nordhagen[††], R. M. Diamond, and F. S. Stephens

Lawrence Radiation Laboratory
University of California
Berkeley, California 94720

August 1969

Abstract

With pulsed beam and electronic timing techniques isomers in ^{156}Gd ($t_{1/2}$ = 2.7 ± 0.1 μsec), ^{172}Yb ($t_{1/2}$ = 3.6 ± 0.1 μsec), and ^{182}W ($t_{1/2}$ = 1.4 ± 0.1 μsec) have been identified. Information on their decays and some tentative spin assignments are given.

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

[††] On leave from the Physics Institute, University of Oslo, Oslo, Norway.

1. Introduction

With the increased use of pulsed-beam techniques and elaborate electronics the number of short-lived isomers found in nuclear reactions is rapidly increasing. Among the isomers of particular interest have been the low-lying, high-spin states found in the even-even rare-earth nuclei. These are believed to be due generally to two-quasi-particle configurations, a noted case being ^{178}Hf with two low-lying $I = 8^-$ states[1]), at 1148 and 1480 keV . Both states consist of mixtures of the two-proton configuration based on the Nilsson orbits $7/2^+[404]$, $9/2^-[514]$, and the two-neutron configuration $9/2^+[624]$, $7/2^-[514]$.

In the course of other work we have found three new, microsecond isomers in the even-even rare earths which probably are additions to this general class of quasi-particle isomeric states. With the experimental procedure mentioned below, a rather systematic survey for μsec isomers in the rare-earth region revealed a large number of isomeric transitions. Among the ones not previously reported, only the three in ^{156}Gd, ^{172}Yb, and ^{182}W were readily identified due to their well known ground-band transition energies, and could be produced with sufficient intensities to permit closer study. Half lives, gamma-ray and conversion-electron spectra were measured, the last of these with rather poor statistics. However, sufficient data were obtained to give a general description of the decays.

2. Experimental Procedure

The three isomers were produced with the α-particle beam of the Lawrence Radiation Laboratory HILAC. In addition to the overall pulsed nature of the beam (duty cycle ∿ 20%) an electrostatic beam pulsing system was employed to produce short beam bursts (down to ∿ 1 μsec duration) at repetitive intervals during the main pulse. For all isomers a beam energy of 27 MeV was used.

For gamma-ray studies, thick targets, mostly of natural composition, were bombarded. In a few cases targets of separated isotopes were also used. The spectra were obtained with Ge(Li) counters of about 6 cm^3 volume, situated at 90° to the beam direction and with front faces a few cm from the target position. The gamma-ray counter pulses were fed to a fast, successive-approximation ADC2) via the LRL amplifying system consisting of a preamplifier, linear amplifier, pile-up rejector and linear gate. The outputs from the ADC were read by a PDP-7 computer, and stored as pulse-height spectra in the computer memory. Additional bits in the ADC were connected to a multiple gate unit. Following each short beam burst, and after an adjustable delay, the gate unit would route the ADC addresses to consecutive subgroups of memory storage. In addition, the gate unit triggered the beam bursts and controlled their duration. Suitable care was taken to avoid subgroup overlap and to obtain uniformity in time, and the delay had to be adjusted to avoid contaminating the subgroup immediately following the beam burst with in-beam gamma rays. The number of subgroups could be up to 7, one additional group always being reserved for the transitions being observed between the main beam pulses. These would be due to long-lived

($t_{1/2} \gtrsim$ milliseconds) activities. The number of subgroups and their length in time determined the repetition interval for the short beam pulses.

The timing in the multiple-gate unit was determined with a calibrated oscilloscope, and in addition a uniformly-running pulse-generator was fed into the system. The integrated pulse-generator pulses in each sub-spectrum gave a measure of the subgroup time uniformity. For the half-life measurements the gamma rays were sorted into 7 subgroups of 512 channels each. For the determination of gamma-ray energies and intensities either 3 groups of 1024 channels (with one group timed in-beam) or 2 groups of 2048 channels (with one group timed between beam-bursts) were used.

The conversion-electron spectra were observed with a 3 mm deep Si(Li) detector coupled to the same electronic system. A solenoidal field at 90° to the beam direction focused the electrons onto the detector. The targets employed in the electron-spectrum measurements were self-supporting or thin carbon-backed foils between 300 and 800 $\mu g/cm^2$ thick. To give a reasonable yield, the target thickness was somewhat larger than desirable for optimum resolution. Consequently, the quality of the electron spectra suffered from the increase in peak width due to the target thickness.

The beam rate in all measurements was limited by the in-beam counting rate, which had to be kept below counter breakdown. With very high rates and short subgroup timing (below 5 - 10 μsec), the gamma-pulse distortion in the first subgroup after the beam could be severe. Here, the pile-up rejector could not be used, as the introduced deadtime (∿ 10 μsec) could seriously affect the counting rate in the first group.

Finally, peak intensities were extracted by various peak-fitting procedures, both on-line and by using the program written for the Berkeley CDC 6600 by Routti and Prussin[3]). Transition energies were obtained by interpolating between lines with known energies.

3. Results and Discussion

3.1. ^{156m}Gd

The information on this isomer, produced via the ^{154}Sm(α,2n)^{156}Gd reaction, is less clear than for the other two. The half-life data are shown in fig. 1, and a half-life of $t_{1/2}(^{156m}\mathrm{Gd}) = 2.7 \pm 0.1$ μsec was obtained. The gamma-ray spectra were obtained by the bombardment of thick targets of natural Sm, and the following relatively strong rays were found to follow the decay: 89.0, 128.6[†], 155.5[†], 199.2, 228.3[†], 296.3, 380.2[†], and possibly 450.8[†] keV. A gamma-ray spectrum is given in fig. 2 and a partial decay scheme in fig. 3, based on the previously known states up to spin 6. The 8 → 6 and 10 → 8 ground-band transitions are assigned on evidence from the spectra observed in-beam, where both lines appear with the same relative intensity to the lower ground-band members as do the corresponding known transitions in the other even-even Gd nuclei. They also follow the level systematics expected for the ^{156}Gd ground band.

In addition to the ^{156m}Gd activity, at least one other isomeric decay is present in the observed spectrum, with a half life long compared to the microsecond-time region but short relative to the millisecond one. The energies involved are 76.0[†], 151.2[†], and 246.8[†] keV. Transitions with energies of 54[††], and 86.6[†] keV appear in both the microsecond region and in the long-lived (millisecond) one.

[†] These gamma energies have errors of ± 0.2 keV relative to the energies of the known ground-band transitions (not marked, from ref. [1]) and the 511.0 keV annihilation line.

[††] ± 1 keV.

Electron spectra were observed, confirming the gamma-ray information, but were not sufficiently good to add much to the decay scheme. The intensities of the ground-band transitions indicate feeding to the three highest states observed, but the decay sequence from the isomeric state could not be determined from the present data.

3.2. ^{172m}Yb

This isomer was studied by means of the ^{170}Er(α,2n)^{172}Yb reaction, mainly on targets of natural Er. For the final gamma-ray spectrum the separated isotope ^{170}Er was used for target material. The transitions observed, with energies and intensities relative to the 78.7 keV transition (100%) are given in table 1. The gamma-ray spectrum is shown in fig. 4, and the decay scheme in fig. 5. Other identified activities observed were trace amounts of the 3.5 μsec, 399 keV isomer in ^{173}Yb, and, in the out-of-beam subgroup, the 2.3 sec, 207.8 keV isomer in ^{167}Er. There was one unidentified transition in the microsecond region of 487.8 keV energy (long lived compared to the ^{172}Yb isomer), and three lines with energies ∿ 55, 106, and 114 keV in the millisecond (or longer) region. The half-life data are given in fig. 1, the observed half life was $t_{1/2}(^{172m}\mathrm{Yb}) = 3.6 \pm 0.1$ μsec.

In the electron spectra it was possible to observe that the intensity of the K-electron line for the 174.6 keV transition was low relative to the same line for the 181.6 keV E2 transition, $I_K(174.6)/I_K(181.6) = 0.6 \pm 0.1$. The same ratio, taking the relative gamma-ray intensities of the two transitions into account, would be for different multipolarities of the 174.6 keV line: E1, 0.5; M1, 4.0; E2, 1.7; M2, 22; E3, 5.3; etc. Evidently then, the 174.6 keV transition has an E1 character. Also, the K/L ratio for the

174.6 keV transition relative to the one at 181.6 keV, appears to be consistent with this assignment.

Most of the decay scheme is reasonably easy to establish, due to the substantial amount of information available on ^{172}Yb[1]), and by making use of the observed intensities. However, the assignment of a level at 1353.5 keV rests solely on transition energies, and is tentative. The E1 character of the 174.6 keV transition limits the spin of the isomeric state to I = 4, 5, or 6, all odd parity. However, it is hard to see why, if the spin were 4 or 5, the energetically favored transitions to the lower spin 3 or 4 states, rather than to the 5 and 6 states, does not occur. Thus, a spin assignment of $I^{\pi} = 6^{-}$ seems favored for the 1551.1 keV state.

Among the nearest even-even nuclei, several two-quasi-particle states with $I^{\pi} = 6^{+}$ are known. These states generally decay both to the spin 6 and 4 states of the ground band, a fact which supports the different assignment of the present isomer, as in ^{172m}Yb no direct transition to the spin 4 ground-band state is seen. Of the several possible combinations of the two quasi-particle configurations found in this mass region, the Nilsson orbits due to the $5/2^{-}$[512] and $7/2^{+}$[633] neutron configurations are most likely the ones giving rise to the isomeric state with $I^{\pi} = 6^{-}$. The same two orbits are the lowest two in the neighboring nucleus ^{173}Yb. It is interesting to note that the 1173.1 keV, two-quasi-particle state is thought to be based mainly on the two lowest orbits in the other neighbor, ^{171}Yb, i.e., the $1/2^{-}$[521] and the $5/2^{-}$[512] configurations[4]), the last being one of the two suggested for the present 1551.1 keV isomeric state. The 174.6 keV E1 transition has a K forbiddeness of ΔK - L = 2, and a retardation factor of 10^{8} relative to a single-particle transition.

3.3. ^{182m}W

Natural targets of Hf were bombarded to produce ^{182m}W, mainly by the $^{180}Hf(\alpha,2n)^{182}W$ reaction. The isomers in ^{181}W ($t_{1/2}$ = 14.4 μsec, E = 365.5 keV), in ^{180}W ($t_{1/2}$ = 5.2 msec, E = 1525 keV), and in ^{179}W ($t_{1/2}$ = 5.2 min, E = 221.8 keV) were also produced. Table 2 gives the energies of all gamma transitions observed and their assignments, and fig. 6 shows the gamma-ray spectrum from the ^{182m}W decay (accumulated for 7 μsec after a 7 μsec beam burst) with the long-lived components (^{180m}W and ^{179m}W) subtracted. The ^{181m}W activity remains. Fig. 7 gives the decay scheme with intensities for the primary transitions, and the half-life data are plotted in fig. 1. The observed half life was $t_{1/2}(^{182m}W) = 1.4 \pm 0.1$ μsec.

The conversion-electron spectrum (taken in 5 μsec after a 5 μsec beam burst) is shown in fig. 8. As can be seen, the K-conversion line of the 518.5 keV transition is clearly present. By comparing with the conversion coefficients of the known E2 transitions in the spectrum, and the gamma-ray intensities, a conversion coefficient of $\alpha_K(518\text{ keV}) = 0.6 \pm 0.2$ is obtained. For the 1086.1 keV transition, no peak due to a K line was seen above background. The background itself, however, was large enough to make it difficult to decide, with sufficient statistical accuracy, whether even a conversion line due to the higher multipolarities (M2) could possibly be present or not.

To establish the sequence of the two transitions of 518.5 and 567.6 keV we note that the 567.6 keV energy is close to the one expected for a 10 → 8 transition in ^{182}W. Moreover, this transition appears in the in-beam spectrum with approximately the same intensity relative to the other ground-band transitions in ^{182}W as shown by the 10 → 8 transition relative to the other ground-band ones in ^{180}W. Also, the 518.5 keV transition is relatively weaker in-beam, as would be expected for an isomeric transition. Finally this latter transition has a conversion coefficient larger than that for an E2, making it an unlikely candidate for the 10 → 8 ground-band transition. We therefore assign $I^{\pi} = 10^{+}$ to the 1711.6 keV state in ^{182}W, and propose the sequence of transitions as shown in the decay scheme.

The α_K for the 518.5 keV transition of 0.6 ± 0.2 could be due to either M1 transition ($\alpha_K = 0.5$), an E1-M2 mixed transition (approx. 50% E1 and 50% M2), or a M2-E3 mixture (approx. 25% M2 and 75% E3). The half life of the isomeric state makes the possibility of an E3 (or M3 and higher) multipolarity for the transition unlikely, as then the transition rate would be several single particle units (∿ 6 for an E3). The maximum spin difference between the isomeric state and the 10^{+} state is then 2, and the minimum spin and the minimum value of K for the isomeric state will thus be 8. The transition should then be highly K forbidden (min. $\Delta K - L = 6$). In the case of a possible M2 component in the 518.5 keV transition the forbiddeness factor would be only 10^{3} relative to an allowed single-particle transition. The minimum expected forbiddeness factor is much larger. It therefore seems highly improbable that the 518.5 keV transition includes an M2 component, and the only remaining assignment is then M1. To further eliminate spin possibilities, the half life of the isomer also rules out a possible M3 multipolarity for the 1086.1 keV transition. The spin of the isomeric state must then be $I^{\pi} = 9^{+}$ or 10^{+}.

As with the other isomers we assume that the (high spin) 2230.5 keV isomeric state in ^{182}W is probably based on a two-quasi-particle configuration. In the neighboring odd nucleus, ^{183}Re, Emmott *et al*.5) observed the $I^\pi = 25/2^+$ isomer ($t_{1/2}$ = 1.0 msec, E = 1907.0 keV) and proposed that the properties of this isomer could be explained by the state having a three-quasi-particle configuration consisting of the single proton in the ground-state orbit $5/2^+[402]$ being coupled to a two-quasi-particle $I^\pi = 10^+$ state. Possible configurations for such a state are the two-neutron configuration based on the orbits $9/2^+[624]$, $11/2^+[615]$ and the two-proton configuration $9/2^-[514]$, $11/2^-[505]$. J. O. Newton[6] has pointed out that the presently observed state is very likely this same $I = 10$ state. In this picture, the 1086.1 keV transition should be the same one as the 193 keV isomeric transition in ^{183}Re. In ^{182}W, this reduced transition probability is 10 times slower than in ^{183}Re, presumably due to a smaller admixture into the isomeric state of the ground-band state with the same spin because of the greater energy separation of the corresponding levels of the two bands.

Finally, it must be pointed out that configurations producing reasonably low-lying $I^\pi = 9^+$ states are also possible. Without further information, such a spin cannot be excluded, although we prefer the assignment $I^\pi = 10^+$.

Acknowledgments

The help and interest of Dr. K. Nakai with the initial phases of this work is gratefully acknowledged. We are greatly indebted to Dr. F. S. Goulding, Dr. D. A. Landis, Dr. L. B. Robinson, and Mr. Fong Gin for their interest and help with the electronics equipment, and to the HILAC crew for providing the required beams. One of us (R.N.) is grateful for additional support from the Royal Norwegian Council for Industrial and Scientific Research.

References

1) C. M. Lederer, J. M. Hollander, and I. Perlman, Table of Isotopes, 6th Edition (John Wiley & Sons, New York, 1967) and references therein

2) L. B. Robinson, F. Gin, and F. S. Goulding, Nucl. Instr. Methods 62 (1968) 237

3) J. T. Routti and S. G. Prussin, University of California Lawrence Radiation Laboratory Report UCRL-17672, to be published.

4) D. G. Burke and B. Elbek, Dan. Mat.-Fys. Med. 36 (1967) 6

5) M. J. Emmott, J. R. Leigh, D. Ward, and J. O. Newton, Phys. Letters 20 (1966) 56

6) J. O. Newton, private communication (1969)

Table 1

Energies and intensities observed in the decay of the ^{172m}Yb, 3.6 μsec isomeric state.

E_γ keV	I_γ [††]	Transition $I_i^\pi \to I_f^\pi$, $K_i \to K_f$
78.7[†]	100	$2^+ \to 0^+$, $0 \to 0$
90.7[†]	25	$4^+ \to 3^+$, $3 \to 3$
112.7[†]	29	$5^+ \to 4^+$, $3 \to 3$
174.6 ± 0.2	70	$(6^-) \to 5^+$, $(6) \to 3$
181.6[†]	50	$4^+ \to 2^+$, $0 \to 0$
197.6 ± 0.2	7	$(6^-) \to$ 1353.5 keV
203.4[†]	38	$5^+ \to 3^+$, $3 \to 3$
279.7[†]	25	$6^+ \to 4^+$, $0 \to 0$
813.5 ± 0.3	2	1353.5 keV $\to 6^+$
912.8 ± 0.3	13	$3^+ \to 4^+$, $3 \to 0$
1003.5 ± 0.3	3	$4^+ \to 4^+$, $3 \to 0$
1011.1 ± 0.3	23	$(6^-) \to 6^+$, $(6) \to 0$
1093.2 ± 0.4	5	1353.5 keV $\to 4^+$
1094.4 ± 0.3	49	$3^+ \to 2^+$, $3 \to 0$
1116.2 ± 0.4	3	$5^+ \to 4^+$, $3 \to 0$

[†] Used as relative standards, taken from ref. [1]).

[††] Relative to $I_{78.7}$. Larger intensities have errors ∿ 10%, weak lines up to ∿ 50%.

Table 2

Energies of transitions observed in delayed activities following the Hf(α,n and 2n)W reaction.

Assigned activity	Energy keV	Transition $I_i^\pi \to I_f^\pi$
^{179}W	221.6 ± 0.2	
^{180}W	103.4 ± 0.2	$2^+ \to 0^+$
	233.7 ± 0.2	$4^+ \to 2^+$
	350.7 ± 0.2	$6^+ \to 4^+$
	390.5 ± 0.2	$8^- \to 8^+$
	450.0 ± 0.2	$8^+ \to 6^+$
^{181}W	365.5†	
^{182}W	100.1†	$2^+ \to 0^+$
	229.3†	$4^+ \to 0^+$
	351.0†	$6^+ \to 4^+$
	464.0 ± 0.2	$8^+ \to 6^+$
	518.5 ± 0.2	isom $\to 10^+$
	567.6 ± 0.2	$10^+ \to 8^+$
	1086.1 ± 0.4	isom $\to 8^+$
β^+	511.0†	

†Used as relative standards, taken from ref. 1).

Figure Captions

Fig. 1. Half-life measurements for the three isomers studied.

Fig. 2. Gamma-ray spectrum, gated on in the microsecond region, following bombardment of natural Sm with alpha particles.

Fig. 3. Partial decay scheme for the 2.7 μs isomer in ^{156}Gd.

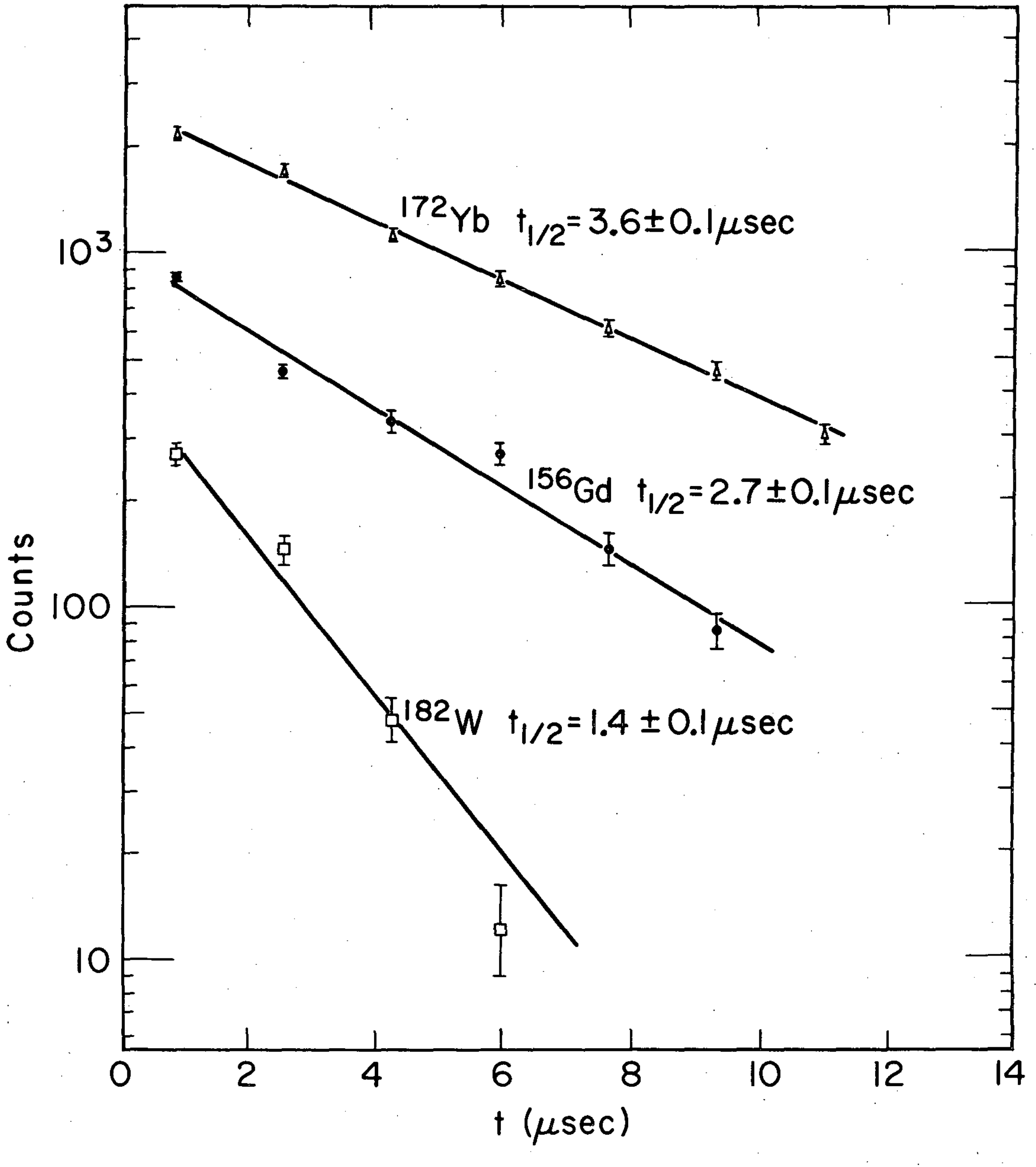
Fig. 4. Gamma-ray spectrum, gated on for 7 μs following a 7 μs beam burst, from bombardment of ^{170}Er with alpha particles.

Fig. 5. Decay scheme for the 3.6 μs isomer in ^{172}Yb.

Fig. 6. Gamma-ray spectrum, gated on for 7 μs following a 7 μs beam burst, from bombardment of natural Hf with alpha particles. The long-lived lines, seen in the ms region, have been subtracted out.

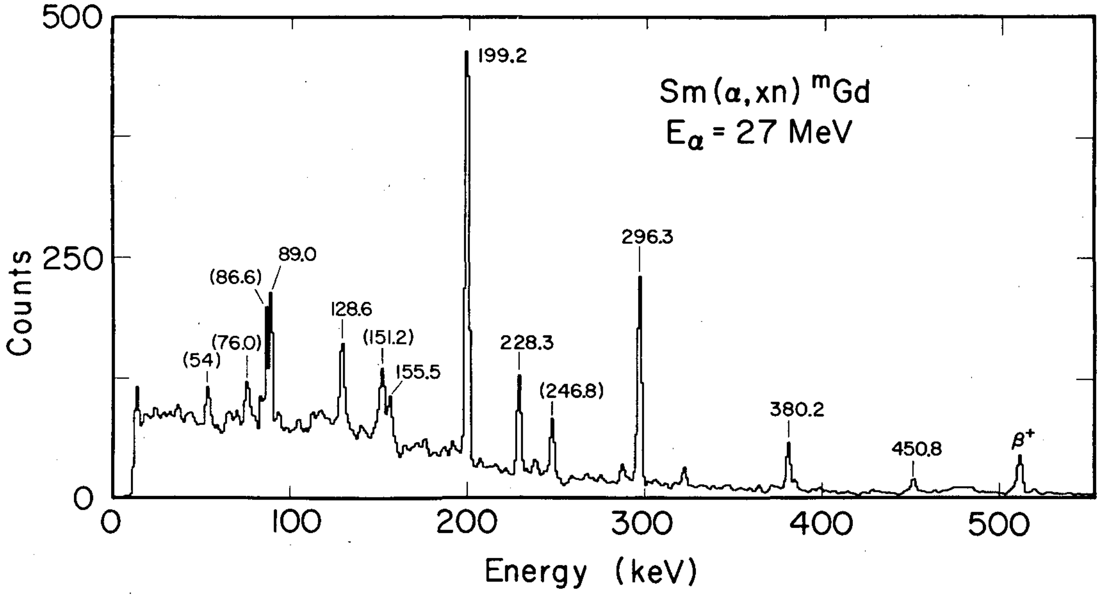
Fig. 7. Decay scheme for the 1.4 μs isomer in ^{182}W.

Fig. 8. Electron spectrum, gated on for 5 μs following a 5 μs beam burst, from bombardment of natural Hf with alpha particles.



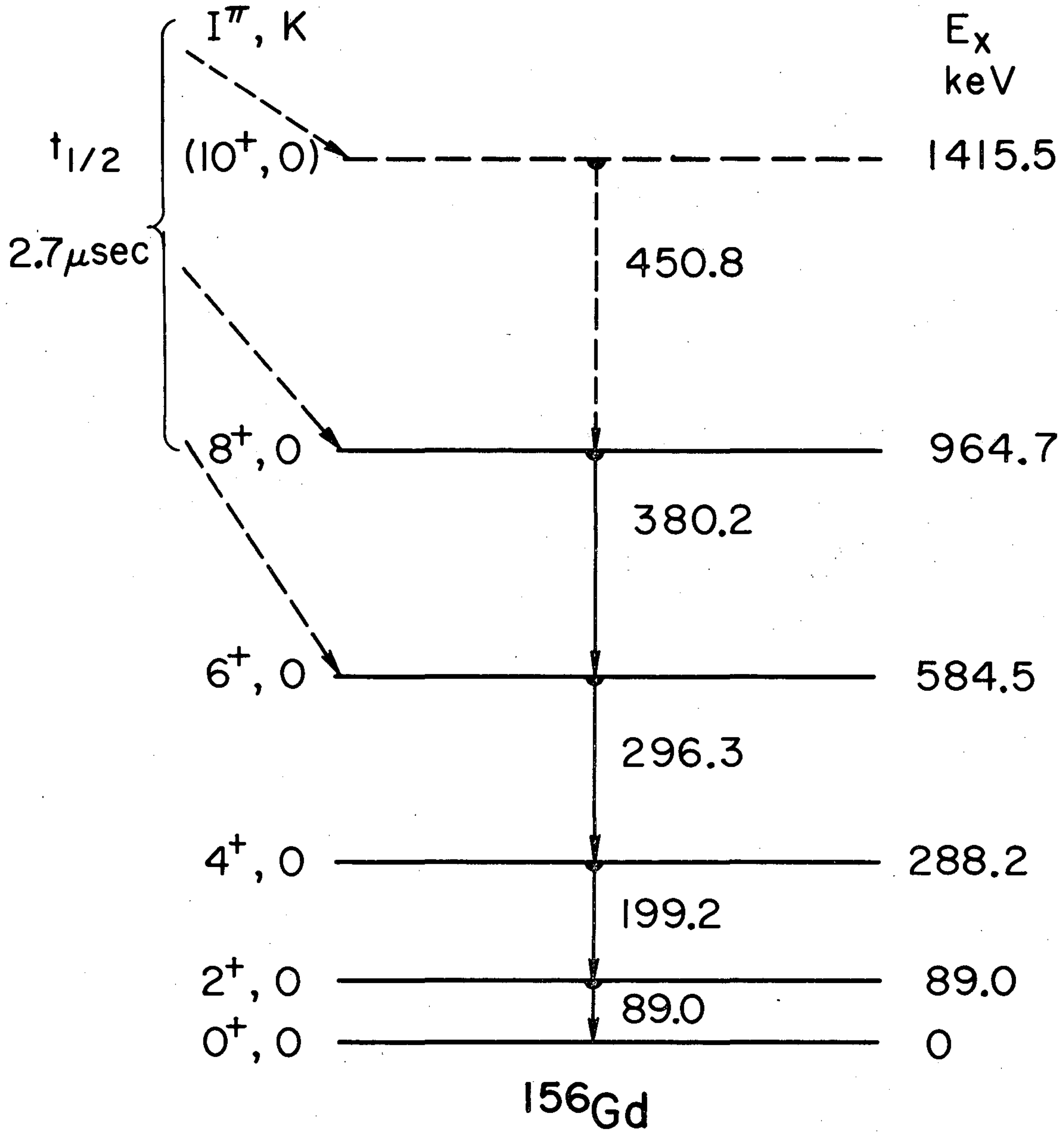
XBL697-3287

Fig. 1



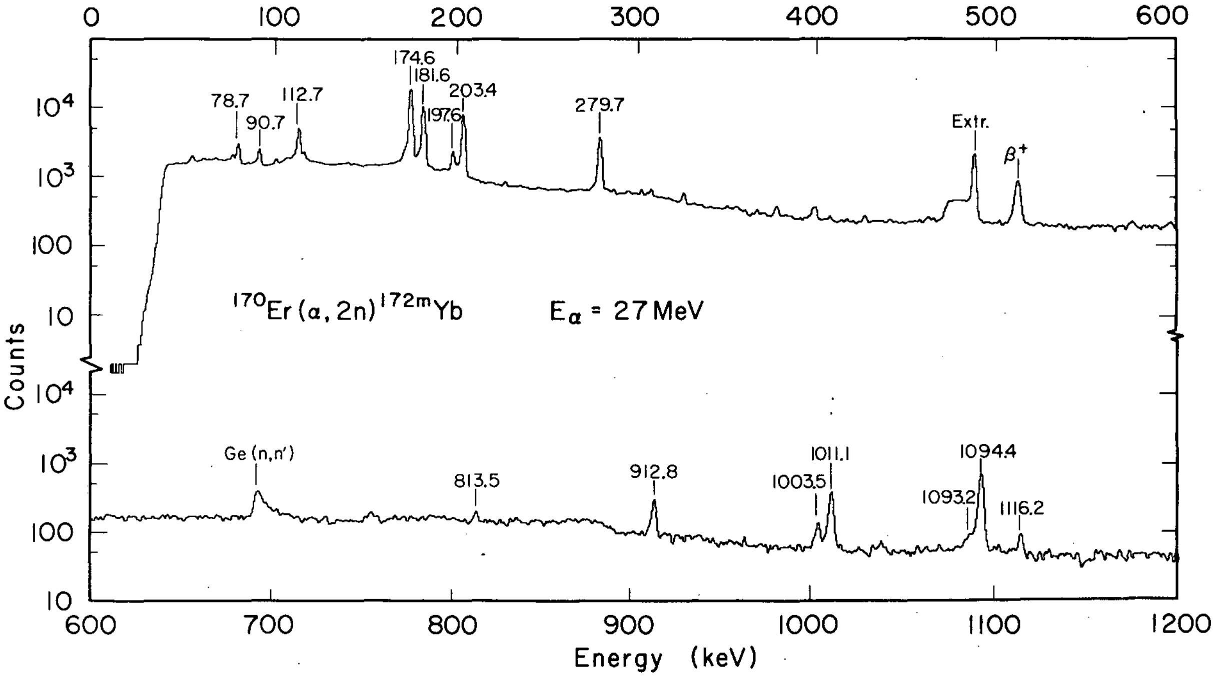
XBL698-3369

Fig. 2



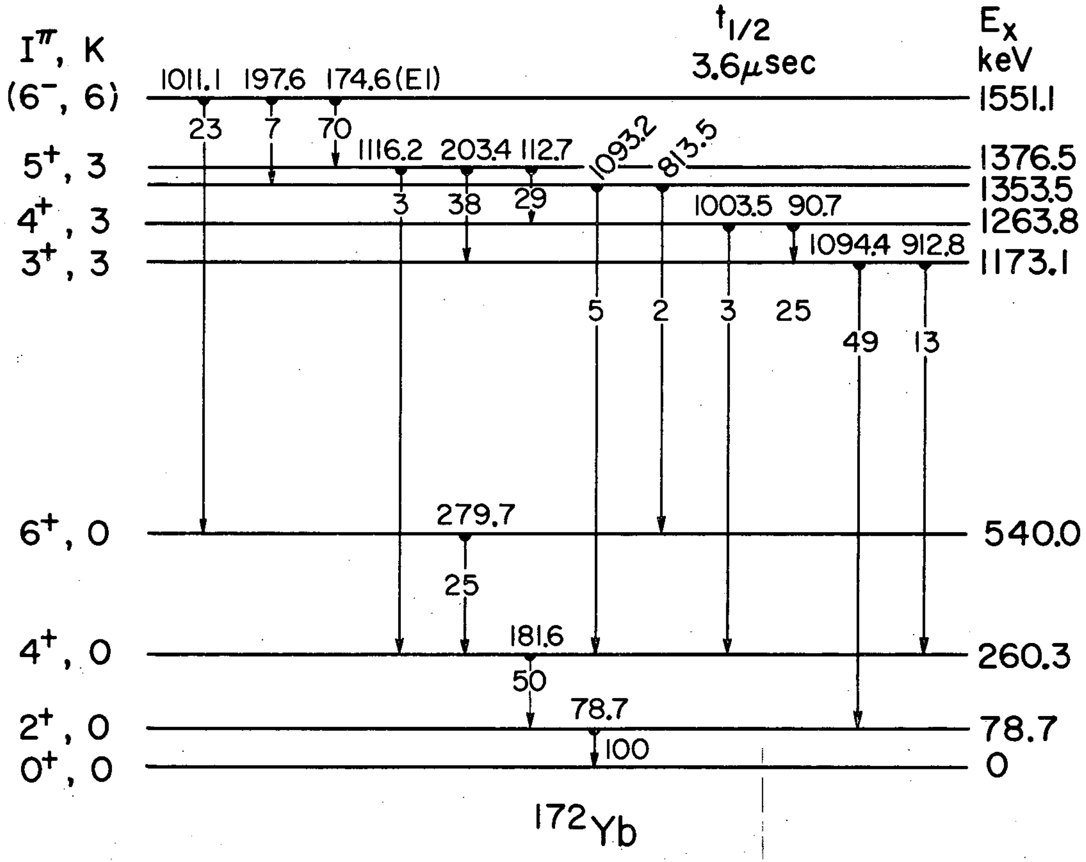
XBL698-3368

Fig. 3



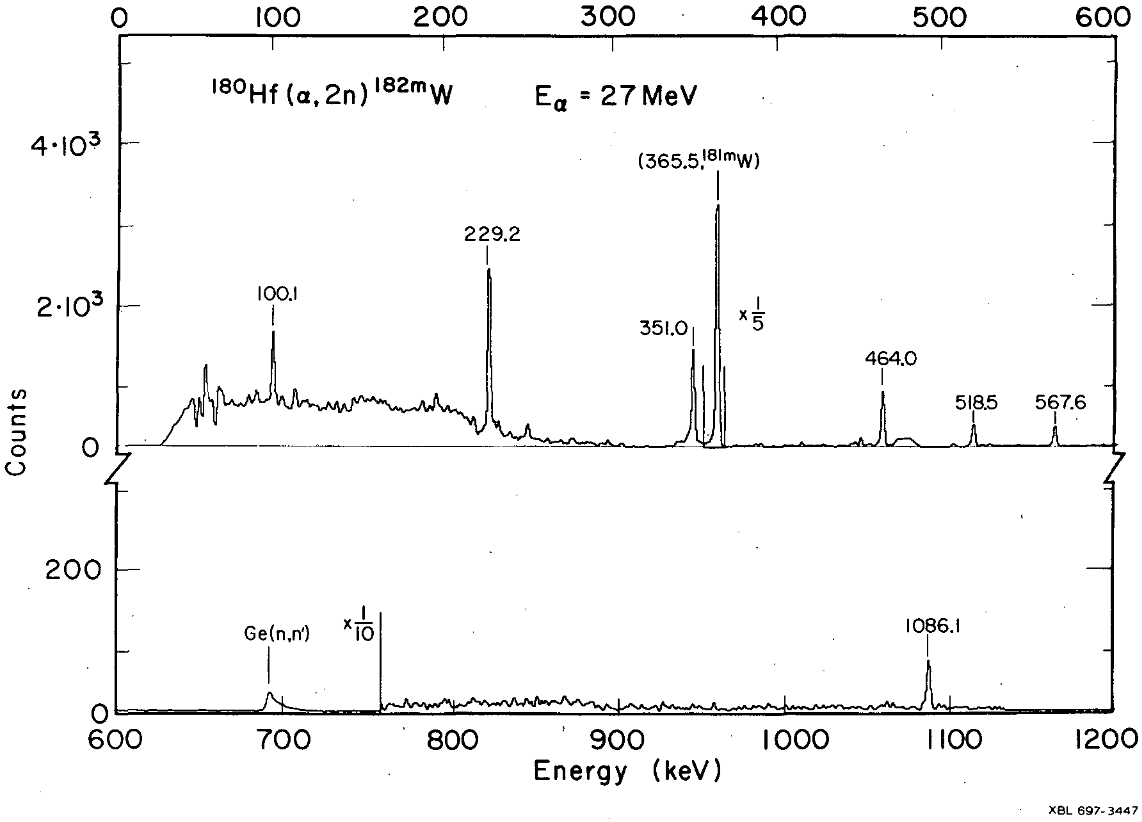
XBL697-3289

Fig. 4



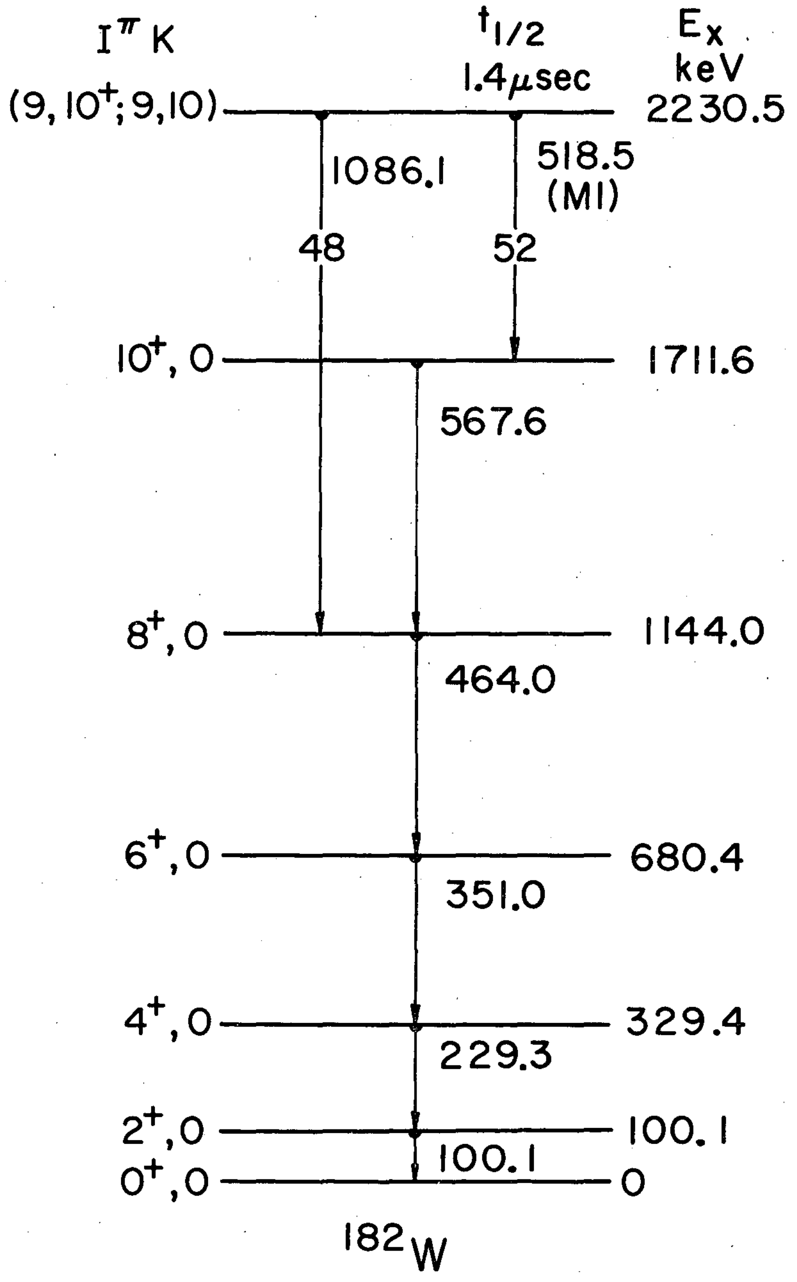
XBL697-3285

Fig. 5



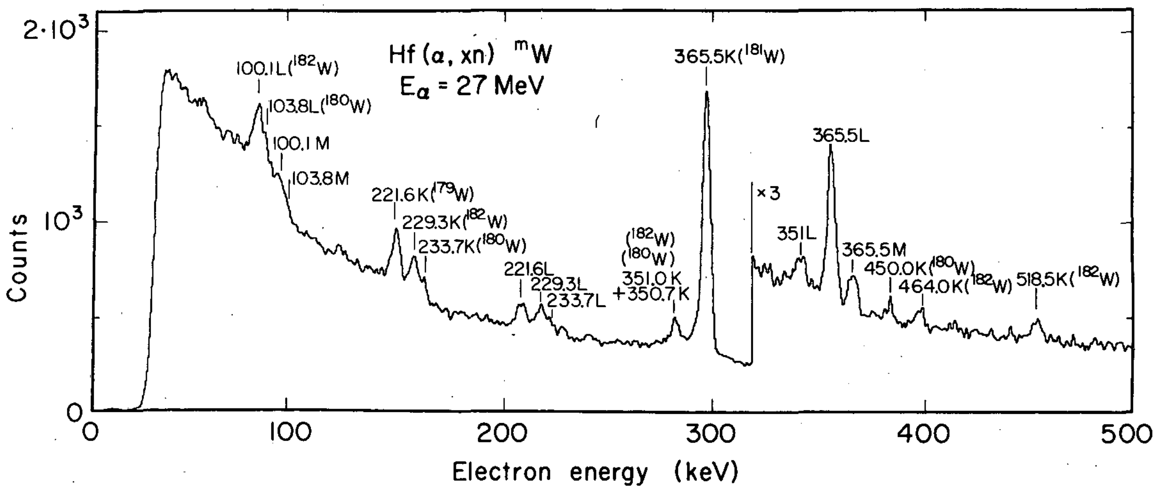
0
100
200
300
400
500
600
^{180}Hf (α, 2n) ^{182m}W
E$_{\alpha}$ = 27 MeV
4·10^{3}
2·10^{3}
0
Counts
(365.5, ^{181m}W)
229.2
100.1
351.0
x 1/5
464.0
518.5
567.6
200
0
Ge(n,n')
x 1/10
1086.1
600
700
800
900
1000
1100
1200
Energy (keV)
XBL 697-3447

Fig. 6



XBL 697-3286

Fig. 7



XBL697-3288

Fig. 8

TECHNICAL INFORMATION DIVISION
LAWRENCE RADIATION LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720