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A $K^{\pi}=0^{+}$ Band in ^{184}W†

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Two high-energy γ rays of 6409±3 and 6290±3 keV, produced following the capture of 7.6-eV neutrons by ^{183}W, populate states in ^{184}W at 1004 and 1123 keV, respectively. The spectrum of γ rays in coincidence with each of these primary γ rays has been measured. These measurements result in an assignment $I^{\pi}=2^{+}$ for the 1123-keV state and suggest that the 1004- and 1123-keV states are the $I^{\pi}=0^{+}$ and 2^{+}members, respectively, of a $K=0$ band. Band-mixing calculations based on the branching ratios for decay of the 1123-keV state to members of the ground-state band have been carried out, and values of the band-mixing parameter z_0 have been derived.

INTRODUCTION

A PREVIOUS examination[1] of the γ rays produced by neutron capture in the 7.6 eV, $I^{\pi}=1^{-}$ resonance of ^{183}W revealed two intense γ-ray transitions with energies of 6409±3 and 6290±3 keV along with many other transitions leading to excited states in ^{184}W. The 1004- and 1123-keV states populated by these two transitions have not previously been reported[2] from β-decay studies, but probably correspond to the states reported at 1.01 and 1.15 MeV in an earlier (n,γ) experiment.[3] These two intense γ rays are almost certainly $E1$ transitions, so the states which they populate can only have $I^{\pi}=0^{+}$, 1^{+}, or 2^{+}. For this reason the state at 1004 keV cannot be identified with the $I^{\pi}=3^{+}$ member of the γ-vibrational band known[2] to be at 1006.5 keV. Since the first excited $K^{\pi}=0^{+}$ band was not observed in the radioactive-decay studies and knowledge of this band is of considerable importance to our understanding of the structure of this nucleus, it is of interest to determine whether the 1004- and 1123-keV states are members of this band. Consequently, the γ rays coincident with the 6409- and 6290-keV transitions have been studied in order to deduce the character of the two states.

EXPERIMENTAL ARRANGEMENT

A crystal spectrometer facility[1] provided monochromatic neutrons for these experiments. Neutron collimation consisted of a 10-min-divergence Soller slit collimator in a primary beam from the Materials Testing Reactor. Neutrons with an energy of 7.6±0.8 eV were obtained by diffraction from the $(10\bar{1}3)$ planes of a Be crystal. The target consisted of a 0.60-in.-thick sheet of 99.9% natural tungsten placed at an angle of 45° to the incident neutron beam. The beam diameter at the target was 1 in.

A coaxially-drifted Ge(Li) detector with an 8 cm^3 active volume was used to resolve the high-energy primary transitions. Figure 1 shows the high-energy singles spectrum of γ rays produced at the 7.6-eV resonance. Numbered peaks are double-escape peaks, but the full γ-ray energy obtained by adding 1022.0

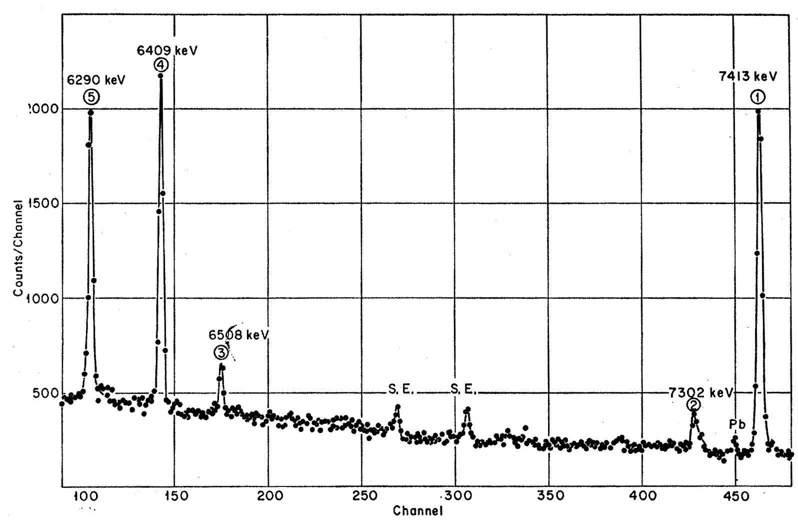

FIG. 1. High-energy ^{184}W γ-ray spectrum from capture of 7.6-eV neutrons, obtained with a Ge(Li) detector.

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[1] R. R. Spencer and K. T. Faler, Phys. Rev. 155, 1368 (1967).
[2] *Nuclear Data*, edited by K. Way (Academic Press Inc., New York, 1966), p. BI-1-65.
[3] L. M. Bollinger, R. E. Coté, R. T. Carpenter, and J. P. Marion, Phys. Rev. 132, 1640 (1963).

keV to the actual energy is indicated in Fig. 1. Small single-escape peaks in the spectrum are labeled S. E. A peak associated with capture in the Pb shielding is labeled. Peaks 1 and 2 represent primary transitions to the 0^+ ground state and the 2^+ first excited state of ^{184}W. Peak 3 represents the transition to the 904-keV, 2^+ γ-vibrational state. The peaks of interest here are those at 6409±3 and 6290±3 keV which represent transitions to the 1004- and 1123-keV excited states, respectively.

A 3×3-in. NaI(Tl) scintillation detector positioned at 180° to the Ge(Li) detector was used to detect γ rays with energies up to 1200 keV. A $\frac{1}{8}$-in. sheet of ^{6}Li-containing hydrocarbon material and a $\frac{1}{8}$-in. sheet of lead served to reduce the neutron low-energy γ ray, and x-ray intensities at the NaI(Tl) detector. Target-to-detector distances (from the center of the target to the front face of the detector) were approximately 2 in. for the Ge(Li) and 3 in. for the NaI(Tl). Separate NaI(Tl) pulse-height spectra were recorded in coincidence with Ge(Li) events corresponding to the energies of (a) peak 4, (b) peak 5, and (c) the continuum between these two peaks (see Fig. 1). The coincidence measurements were carried out with a standard fast-slow coincidence system with a resolving time of 50 nsec. The data were collected in one quadrant of a multi-channel analyzer. The window width in the Ge(Li) channel was approximately twice the peak widths (full width at half-maximum) in all three spectra. For experiments (a) and (b) above, the counting rate in the Ge(Li) window was approximately 13 per min. For a maximum rate of 10^4 per sec in the NaI(Tl) detector, the chance coincidence rate was less than 5% of the total coincidence rate. Each of the three spectra required approximately a 1-week running time. The continuum between peaks 4 and 5 contains approximately 40% Compton events related to primary ground-state transitions which are not in coincidence with other ^{184}W γ rays. The remaining portion of the continuum contains about equal portions of Compton events associated with peak 4, peak 5, and other ^{184}W γ rays. At the window setting corresponding to either peak 4 or peak 5, approximately 80% of the coincident pulses are associated with the transition of interest. Indeed, the NaI(Tl) spectrum recorded in coincidence with the continuum was almost featureless, showing only very weak transitions in the region of interest and these are accounted for by coincidences with the Compton-scattered γ rays from the high-energy transitions.

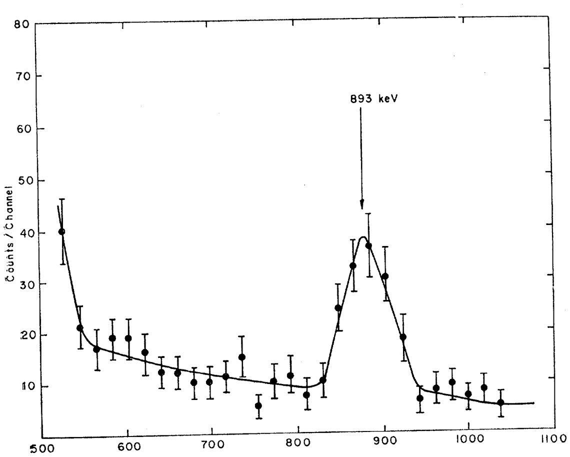

FIG. 2. NaI(Tl) spectrum of γ rays de-exciting the 1004-keV level.

COINCIDENCE DATA

A portion of the γ-ray spectrum obtained in coincidence with the 6409-keV transition is shown in Fig. 2. The most intense radiations registered in the NaI detector were 511-keV annihilation photons from events giving rise to the double-escape peak in the Ge(Li) detector. Above this energy the spectrum contains a single 893-keV photopeak which corresponds in energy to a transition from the 1004-keV excited state to the 111-keV, 2^+ member of the ground-state band. This decay mode suggests $I^\pi=0^+$ as the most likely of the three possible assignments for the 1004-keV state.

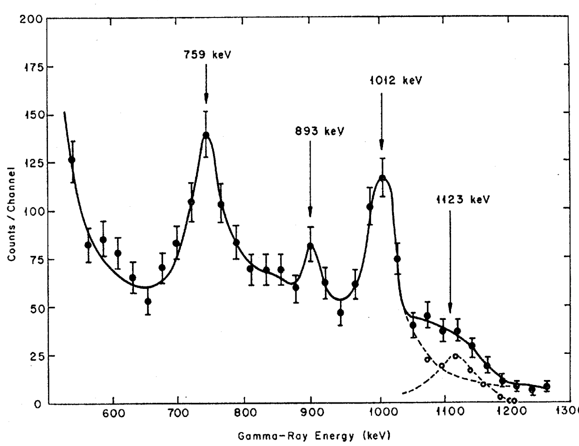

FIG. 3. NaI(Tl) spectrum of γ rays de-exciting the 1123-keV level.

Figure 3 shows the energy region above the 511-keV annihilation peak in the γ-ray spectrum coincident with the 6290-keV transition. Below this energy only peaks corresponding to the expected 111- and 253-keV intraband transitions in the ground-state band were observed. The small peak at 893 keV corresponds to coincidences with the Compton distribution of primary transitions to the 1004-keV state discussed above. Three photopeaks at 1123, 1012, and 759 keV with relative intensities of 20±5, 41±5, and 39±7, respectively, correspond to transitions to the 0^+, 2^+, and 4^+ members of the ground-state band; therefore, the

1123-keV state must have $I^\pi=2^+$. Figure 4 summarizes the experimental results.

DISCUSSION

The most reasonable interpretation for the 1004- and 1123-keV states is to assume they are the $I^\pi=0^+$ and 2^+ members, respectively, of a $K=0$ band. The energy separation of the two states, 8 keV larger than in the ground-state band, is reasonable for a $K=0$ band.

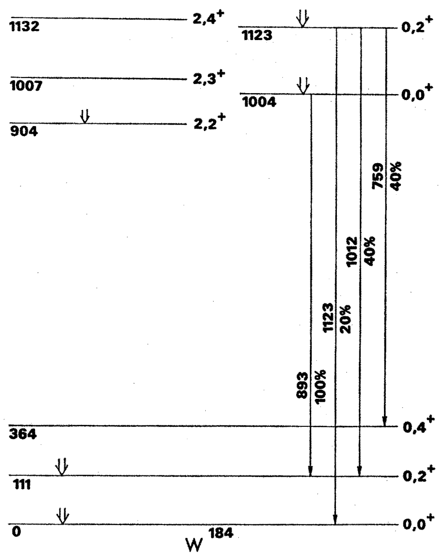

FIG. 4. Partial level diagram of ^{184}W showing the decay scheme of the 1004- and 1123-keV levels with experimental relative intensities for the observed γ rays from these two levels. Primary transitions are indicated by broad arrowheads.

The reduced relative intensities of the γ rays depopulating the 1123-keV state are significantly different from those predicted by the Alaga branching rules.[4] It is well known that the branching ratios for depopulation of the members of vibrational bands to members of the ground-state band are affected by mixing of the

TABLE I. Experimental ratios of reduced $E2$ transition probabilities for the 1123-keV state and the derived values of the band-mixing parameter z_0.

Reduced relative transition probability	Experimental ratio	$-10^2 z_0$
$\frac{B(E2{:}0,2\to0,4)}{B(E2{:}0,2\to0,2)}$	3.53±0.81	2.9±1.2
$\frac{B(E2{:}0,2\to0,0)}{B(E2{:}0,2\to0,2)}$	0.30±0.08	5.8±1.5

bands.[5] The effect of this mixing on the branching ratios is expressed in terms of a parameter z_0. Assuming that the 1123-keV state is a member of a vibrational band and using our data on the decay of the 1123 keV, $I^\pi=2^+$ state in ^{184}W, we have calculated values of z_0 which are given in Table I along with the derived relative $B(E2)$ ratios. The error limits on the ratios represent only the statistical uncertainty from the number of counts collected. Although the two derived values for z_0 differ by a factor of 2, the error limits nearly overlap. Clearly, the variation in z_0 is considerably less than that found in the cases of ^{152}Sm and ^{154}Gd.[6] However, in view of the relatively large uncertainties and the fact that we have been able to study the depopulation of only one rotational member of the band, it is not possible to determine the full extent to which the band-mixing treatment can explain the relative intensities for depopulation of the first excited $K^\pi=0^+$ band in ^{184}W.

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[4] G. Alaga, K. Alder, A. Bohr, and B. Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-Fys. Medd. **29**, No. 9 (1955).

[5] O. Nathan and S. G. Nilsson, in *Alpha-, Beta-, and Gamma-Ray Spectroscopy*, edited by Kai Siegbahn (North-Holland Publishing Co., Amsterdam, 1965), Chap. X.

[6] L. L. Riedinger, N. R. Johnson, and J. H. Hamilton, Phys. Rev. Letters **19**, 1243 (1967).