PHYSICAL REVIEW C VOLUME 12, NUMBER 3 SEPTEMBER 1975

Isomerism in ^{194}Au†

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(Received 22 May 1975)

Isomeric states in ^{194}Au with half-lives of 600 ± 8 and 420 ± 10 ms have been studied by observing the delayed γ rays following the ^{194}Pt(p,n) and ^{194}Pt$(d,2n)$ reactions. γ-ray singles and γ-γ coincidence measurements were made and isomer cross section ratios were calculated. It is argued that the isomer at 80.5 keV has the shell model configuration $(\pi d_{3/2}, \nu i_{13/2})5^+$, while the higher-lying isomer is believed to decay by an unobserved isomeric transition.

[RADIOACTIVITY ^{194}Au (isomeric levels) [from ^{194}Pt$(d,2n)$, ^{194}Pt(p,n)]; measured E_γ, I_γ, $T_{1/2}$, γ-γ coin, isomer ratios. Natural and enriched targets. Calculated isomer ratios, deduced shell model assignments.]

In recent years long-lived $J^\pi=12^-$ $(\pi h_{11/2}, \nu i_{13/2})$ isomers have been discovered[1-6] in the gold isotopes ^{196}Au, ^{198}Au, and ^{200}Au. In experiments designed to observe ^{192,194,202}Au isomeric activities with half-lives longer than 5 min, no new isomers were found.[7] While the high decay energy anticipated for an isomer of ^{202}Au may explain why it was not seen, the nonobservance of long-lived ^{192}Au and ^{194}Au isomers proves somewhat more difficult to understand and fosters a desire to extend the search to shorter lifetimes.

In the present measurements we have observed isomers in ^{194}Au with half-lives of 600 ± 8 and 420 ± 10 ms (see Fig. 1) using pulsed beam techniques.[8] These activities were produced by the $(d,2n)$ and (p,n) reactions on natural Pt metal as well as on enriched (83%) ^{194}Pt targets. The γ-ray data for the isomers of ^{194}Au are summarized in Table I. Figure 2 shows the γ-ray spectra obtained at three deuteron energies in the 0.3- to 1.7-s time interval following the beam pulse. These spectra indicate that the shorter-lived isomer lies higher in energy (if it is assumed that one isomer decays to the other) and is of higher spin. The (p,n) reaction at 11-MeV bombarding energy populates the shorter-lived isomer very weakly and lends further support to the probability that this isomer is of higher spin than the 600-ms isomer. γ-γ coincidence measurements show the 129- and 171-keV γ rays as well as the 137- and 162-keV γ rays to be in coincidence, but none of these γ rays are coincident with the 35- or 45-keV γ rays.

The decay scheme shown in Fig. 3 is based on the present data and is constructed using transition multipolarities (see Table I) deduced from intensity balance arguments for the transitions populating and deexciting the levels at 35.3, 217.7, and 251.3 keV. It should be noted that, using the deduced multipolarities for the four higher energy γ rays, the calculated K x-ray yield is in good agreement with the observed yield.

The ground state of ^{194}Au has been determined to have spin $J=1$ from atomic beam measurements[9] and from the shell model should have $J^\pi=1^-$ with a major contribution from the $(\pi d_{3/2}, \nu p_{1/2})$ configuration. From intensity balance arguments the 35- and 45-keV transitions are most likely $E2$ and $M2$, respectively, with the $M2$ transition lifetime estimate[10] slightly more in accord with the observed half-life of the lower-lying isomer. The 35- and 81-keV levels are thus assigned spin-parities of (3^-) and (5^+), respectively. The $(\pi d_{3/2}, \nu i_{13/2})$ 5^+ state has been observed[2,4] as an isomeric state in both ^{196}Au and ^{198}Au, and the isomerism of the 81-keV state in ^{194}Au could be due to either of the

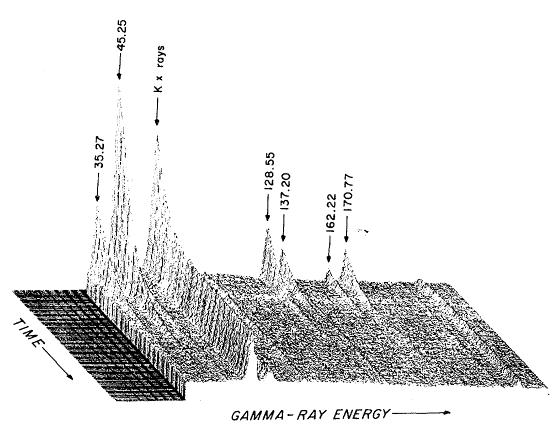

FIG. 1. Isometric plot of data obtained with 15-MeV deuterons incident on an enriched ^{194}Pt target. The delayed γ rays were observed with an 11-cm^3 intrinsic Ge detector and γ rays ascribed to the ^{194}Au isomers are labeled. The time after the beam pulse is given on the time axis (6.7 s full scale).

TABLE I. γ rays observed in the decays of the ^{194}Au isomers.

Energy (keV)	Relative γ ray intensity [b]	Probable multipolarity	Total conversion coefficient [a] α_T	Half-life [c] (ms)
35.27 ± 0.08	$80\ \pm23$	$E2$	712	590 ± 18
45.25 ± 0.09	100	$M2$	728	$602\pm\ 9$
128.55 ± 0.12	100	$E2$	1.94	422 ± 14
137.20 ± 0.14	64.6 ± 5.2	$E2$	1.49	422 ± 22
162.22 ± 0.16	35.5 ± 4.1	$M1$	1.84	420 ± 32
170.77 ± 0.12	101.8 ± 7.1	$M1$	1.61	415 ± 21

[a] R. S. Hager and E. C. Selzer, Nucl. Data A4, 1 (1968).
[b] Intensities of γ rays from the 600- and 420-ms isomers are given relative to the 45.25- and 128.55-keV γ rays, respectively.
[c] Errors indicated include only statistical contributions.

l-forbidden neutron transitions $i_{13/2}\rightarrow f_{5/2}$ or $i_{13/2}\rightarrow p_{3/2}$. The coincident γ rays, 171-129 keV and 162-137 keV, quite plausibly occur between the 8^+ and 5^+ members of the $(\pi d_{3/2}, \nu i_{13/2})$ multiplet. It is not possible to establish the order of these γ rays from the available information, but it seems likely that these intermediate levels are the 6^+ and 7^+ members of the quartet.

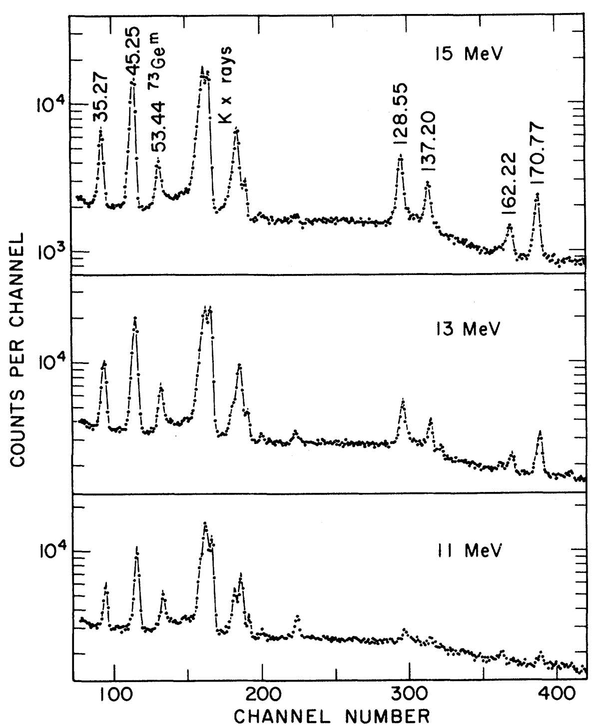

FIG. 2. γ-ray spectra from the $(d, 2n)$ reaction measured at bombarding energies of 11, 13, and 15 MeV. The spectra were obtained with an 11-cm^3 intrinsic Ge detector in the time interval 0.3 to 1.7 s following the beam pulse.

If the 8^+ level has the proposed configuration, it is improbable that this level is an isomeric state. A possible explanation would be that an unobserved isomeric transition occurs between the higher-lying isomer and the 8^+ level with the isomer having $J>8$. From the observed lifetime the isomeric transition cannot be of $M4$ multipolarity; thus the isomer is probably not the $(\pi h_{11/2}, \nu i_{13/2})$ 12^- isomer seen in the other even-mass Au isotopes. Indeed, the lifetime is most consistent with a transition of low energy and $E2$, $M2$, or $E3$ multipolarity.[10] It is then inferred that the isomer has a spin of 10 or 11.

Some further indication of the spin of the higher-lying isomer can be obtained by comparing the experimental cross section ratios for population of the isomers by the (p,n) and $(d,2n)$ reactions with those calculated using the statistical model ap-

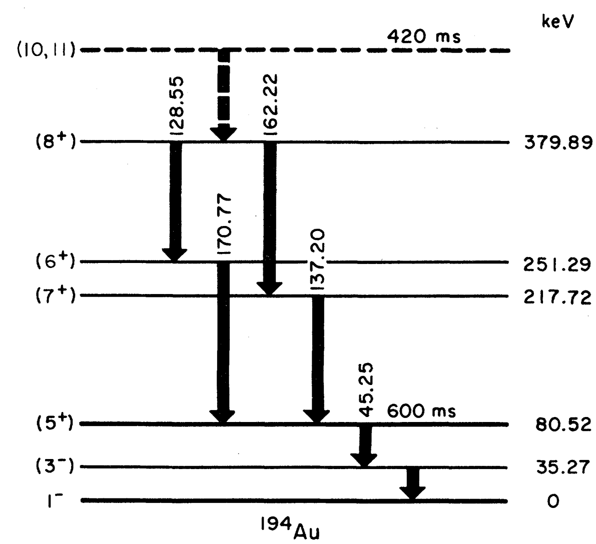

FIG. 3. The proposed decay scheme of the ^{194}Au isomers.

TABLE II. Isomer cross section ratios in ^{194}Au.

	Reaction			
	(p,n)	$(d,2n)$		
	11 MeV	11 MeV	13 MeV	15 MeV
σ_H/σ_5 Experimental [a]	4.0×10^{-4}	1.3×10^{-4}	2.6×10^{-3}	3.8×10^{-3}
σ_8/σ_5 Calculated [b]	5.6×10^{-2}	1.4×10^{-1}	1.9×10^{-1}	2.6×10^{-1}
σ_{11}/σ_5 Calculated [b]	4.6×10^{-4}	3.2×10^{-3}	6.8×10^{-3}	1.3×10^{-2}

[a] σ_H/σ_5 gives the experimentally determined isomer ratio of the higher-lying isomer to the lower-lying, presumably 5^+, isomer.

[b] σ_8/σ_5 and σ_{11}/σ_5 give the calculated results when it is assumed that the higher-lying isomer is of spin 8 or spin 11, respectively.

proach of Vandenbosch and Huizenga.[11] The results of these calculations as computed with the statistical model code SPINDIST[12] are given in Table II for the case where the spin of the higher-lying isomer is assumed to be either 8 (i.e., the 380-keV state is isomeric) or 11 and the lower-lying isomer is $J=5$. The charged particle transmission coefficients were calculated using the optical model code ABACUS[13] and the parameters of Siemssen and Erskine,[14] while the calculations of Feld *et al.*[15] were used for the evaporated neutrons. Clearly the experimental isomer ratios compare more favorably with the calculations for a spin of 11 and support the previous suggestion that the isomer is of higher spin and deexcites by an unobserved isomeric transition.

From the available information it is not possible to suggest a configuration for the higher-lying isomer, although it would be expected that either $\nu i_{13/2}$ or $\pi h_{11/2}$ would be a component in this configuration. Recently, the role of the low-lying $\frac{9}{2}^-[505]$ state which is derived from the $\pi h_{9/2}$ shell model state has been pointed out in the light odd-A Tl nuclei.[16] It is quite plausible that this orbital might also be important in the low energy level spectra of the Au nuclei, but no further speculation is merited from the present information.

We gratefully acknowledge the help of Dr. R. E. Holland and Dr. A. M. Friedman in performing the experiments. We also wish to thank Dr. P. J. Daly and Dr. J. C. Cunnane for valuable discussions and for providing the enriched ^{194}Pt target.

†Work performed under the auspices of the U.S. Energy Resources Development Administration.
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