Decay of Au^{200} (48 min)*

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γ radiation from the decay of Au^{200} has been measured in the energy range from 0.2 to 2 MeV with a 30-cm^3 coaxial-type lithium-drifted germanium detector. Fifteen γ rays attributable to Hg^{200} were observed. Levels at 1570, 1593, and 1631 keV in Hg^{200} are strongly populated via β decay. Weak feeding is suggested for levels at 1718, 1883, 1972, and 2061 keV. The β branch to the 2+ level at 368 keV was found to be <8%; and the β branches to the 4+ level at 947 keV, to the 0+ level at 1029 keV, and to the 2+ level at 1254 keV were found to be <0.2%, <0.5%, and <0.2%, respectively. The results favor spin and parity 1− for the ground state of Au^{200}. Instead of a single 1225-keV line reported in the literature, a doublet with an energy difference of 37 keV was found. Also, instead of a single 1.6-MeV γ ray known from scintillation spectrometer work, a group of γ rays with energies between 1.5 and 1.7 MeV was observed.

I. INTRODUCTION

A RELATIVELY small amount of information on levels in Hg^{200} has been obtained in previous studies of the decay of Au^{200} (48 min). Butement and Shillito[1] observed γ radiation from the decay of Au^{200}. Roy and Roy[2] and Girgis, Ricci, and Van Lieshout[3] studied this decay in greater detail. Roy and Roy measured the half-life of Au^{200} as 48.4 min, and found that the decay proceeds with 75% probability to the ground state, with less than 3% probability to the 370-keV level, and with 25% probability to a level at 1595 keV.[2] They observed three γ rays, with energies of 367, 1230, and 1600 keV, respectively. Girgis *et al.*[3] obtained essentially the same results as Roy and Roy for the energies and intensities of the γ rays. Both Roy and Roy and Girgis *et al.* concluded that the 1600-keV γ ray constitutes the crossover transition from the 1595-keV level to the ground state. In these experiments, scintillation counters were used for the detection of the γ radiation. Girgis *et al.* determined the disintegration energy of Au^{200} to be (2.20±0.10) MeV.

In view of the complexity of the decay[4] of Tl^{200} to Hg^{200} and the great number of excited states in Hg^{200} below 2.2 MeV,[5] it appeared probable that additional levels are populated in the β decay of Au^{200}. Therefore, we have measured the γ spectrum from this decay with a lithium-drifted germanium detector.

II. EXPERIMENTAL METHODS

A. Target Preparation

Ten mg of platinum containing 56.82% Pt^{198} were irradiated for about 30 h in the high-flux zone (thermal and epithermal flux each 6×10^{14} n/cm^2 sec) of the Brookhaven high-flux beam reactor (HFBR). Pt^{200} (11.5 h) was formed through double neutron capture, constituting a rather small fraction of the total activity produced during the irradiation. Most of the activity was Pt^{199} and its daughter product Au^{199}. The following method was applied to isolate Au^{200}: After removal of the sample from the irradiation thimble in the HFBR, it was allowed to cool for about 10 h until the Pt^{199} (31 min) had decayed to Au^{199} to a sufficient extent. The procedure followed in the initial separation of 3-day Au^{199} from the irradiated Pt^{198} sample and the subsequent repeated milking of 48-min Au^{200} was similar to that employed in previous experiments.[2] The Pt sample was dissolved in *aqua regia*, Au carrier was added, and the Au extracted into ethyl acetate. The ethyl acetate fraction was washed twice with 6*N* HCL and taken to dryness for counting.

B. Equipment

The γ radiation was measured with a 30-cm^3 coaxial-type Ge(Li) detector.[6] The pulses were amplified by a field-effect transistor preamplifier and an Ortec amplifier (model 410) and were then stored in a 4096-channel TMC analyzer.

C. Evaluation of Data

The data were processed with the aid of a computer program, which performs a least-squares fit of each spectrum peak to a Gaussian line shape.[7] The energies of the transitions were determined through internal calibration with the 367.97-keV line,[8] the lines[9] from the decay of Co^{60}, and the background lines from the decay of radiothorium[9] and K^{40}.[10,11] The γ-ray intensities

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[2] J. C. Roy and L. P. Roy, Can. J. Phys. **37**, 385 (1959).
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[5] O. W. B. Schult, W. R. Kane, M. A. J. Mariscotti, and J. M. Simić, Phys. Rev. **164**, 1548 (1967).
[6] This detector has been prepared for us by Dr. H. Kraner at the BNL Instrumentation Department. We are very much indebted to Dr. Kraner for his invaluable help and cooperation.
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[10] A. W. Sunyar (private communication).
[11] B. L. Robinson, Phys. Rev. **134**, B506 (1964).

TABLE I. γ transitions from the decay of Au^{200}. The symbol ($\sim$) indicates that the energy uncertainty exceeds 3 keV or that the intensity error is greater than 30%.

	Present work				Roy and Roy[a]			Girgis, Ricci, and Van Lieshout[b]		
	E_γ (keV)	dE_γ (keV)	$I_\gamma$rel	dI_γ/I_γ (%)	E_γ (keV)	dE_γ (keV)	$I_\gamma$rel	E_γ (keV)	dE_γ (keV)	$I_\gamma$rel
c	367.97	0.02	100.	10	367	5	100	370	5	100
c	563.8	...	<1.0	...						
c	579.37	...	<1.0	...						
c	601.1	...	<0.7	...						
	660.9	1.0	2.2	...						
c	886.27	...	<0.7	...						
d	1149.1	1.5	0.3	$\sim$						
	1203.2	1.5	1.9	30						
	1225.90	0.25	68	10	1230	10	100	1225	5	80
	1263.08	0.25	17	10						
d	1494.7	2.0	0.5	$\sim$						
d,e	1507.0	3.0	0.3	$\sim$						
e	1516.0	2.0	0.9	$\sim$						
	1570.6	1.5	2.5	30						
d,f	1593	$\sim$	0.2	$\sim$						
	1604.2	3.0	1.0	$\sim$	1600	20	5	1600	10	2
	1631.8	1.5	1.6	30						
	1695	3	0.7	$\sim$						
	1722	$\sim$	0.3	$\sim$						

[a] Reference 2.
[b] Reference 3.
[c] The energy values have been taken from Maier *et al.* (Ref. 8).
[d] The γ transition has been observed in this experiment as a very weak peak and its existence should therefore be considered as questionable.
[e] The peak corresponding to this γ transition has not been isolated from a neighboring peak in the pulse-height spectrum.
[f] The double-escape peak of the 2614-keV transition from the decay of radiothorium (background) overlaps with the full energy peak of this transition.

were determined from an efficiency curve obtained with the use of the radioactive sources Bi^{207} and Na^{22} and their known γ intensity ratios.[12]

III. RESULTS

The energies and relative intensities of the transitions observed, as well as their errors, are listed in Table I. Upper limits are given for some γ transitions which are known to occur between low-lying states in Hg^{200} from the results of (n,γ) experiments.[8] It is found that the energies of the transitions seen in this experiment agree well with those measured previously[5] by (n,γ) studies.

From Table I, it is seen that both the 1225- and 1600-keV peaks observed in earlier work[2,3] actually correspond to unresolved γ-ray multiplets. Two rather intense γ rays with energies of 1225 and 1263 keV are present instead of the single 1225-keV line which had been observed with scintillation counters. [Even a shape analysis of the peak corresponding to a (1225 ± 5)-keV transition in the pulse-height spectrum had not given any evidence for a satellite.][3] The center of gravity of the 1570-, 1593-, 1604-, and 1631-keV transitions is 1593 keV, which explains the result of the low-resolution studies.[2,3] Table I further shows that the transition which was reported in earlier work[2–4] and which was interpreted[2–4] as leading from the 1600-keV level to the ground state is very weak.

[12] *Nuclear Data Sheets*, complied by K. Way *et al.* (U. S. Government Printing Office, National Academy of Sciences—National Research Coincil, Washington, D. C.) NRC 20418.

IV. DECAY SCHEME

A comparison of the energies and branching ratios of the transitions listed in Table I with recent results obtained in studies of the $Hg^{199}(n,\gamma)Hg^{200}$ reaction[5] supports the level diagram of Hg^{200} shown in Fig. 1. All of the levels shown, except for the 1972.7-keV level, which is seen in the Tl^{200} decay,[4] are populated following neutron capture by Hg^{199}. The results obtained for Au^{200} are in complete accord with the assignments made in the neutron capture and Tl^{200} studies, and thus serve to confirm conclusions drawn from the more complex results of the latter work.

The 1570.40-keV level is one member of a closely spaced doublet of levels, at 1570.40 and 1573.85 keV, respectively. The 1570.40-keV level is seen to decay by a 1203.2-keV transition to the first excited state and by a 1570.6-keV ground-state transition. The 1573.85-keV level is populated in the decay of Tl^{200}. It is de-excited by an intense 1206.8-keV transition to the first 2+ state and probably by weak transitions to the ground state and to the 1029-keV level.[4] Both levels are populated, more or less equally, in the neutron capture reaction. The capture γ-ray spectrum thus exhibits a broadened peak at $\sim$1205 keV corresponding to the 1203.2- and 1206.8-keV lines and a peak at 1570.3 keV, whose principal component is the ground-state transition from the 1570.40-keV level, but which may also have a much weaker 1573.85-keV component. On this basis the 1203.2- and 1570.6-keV transitions were identified as originating from the 1570.40-keV level.[5] This assignment is borne out by the present results, in which only

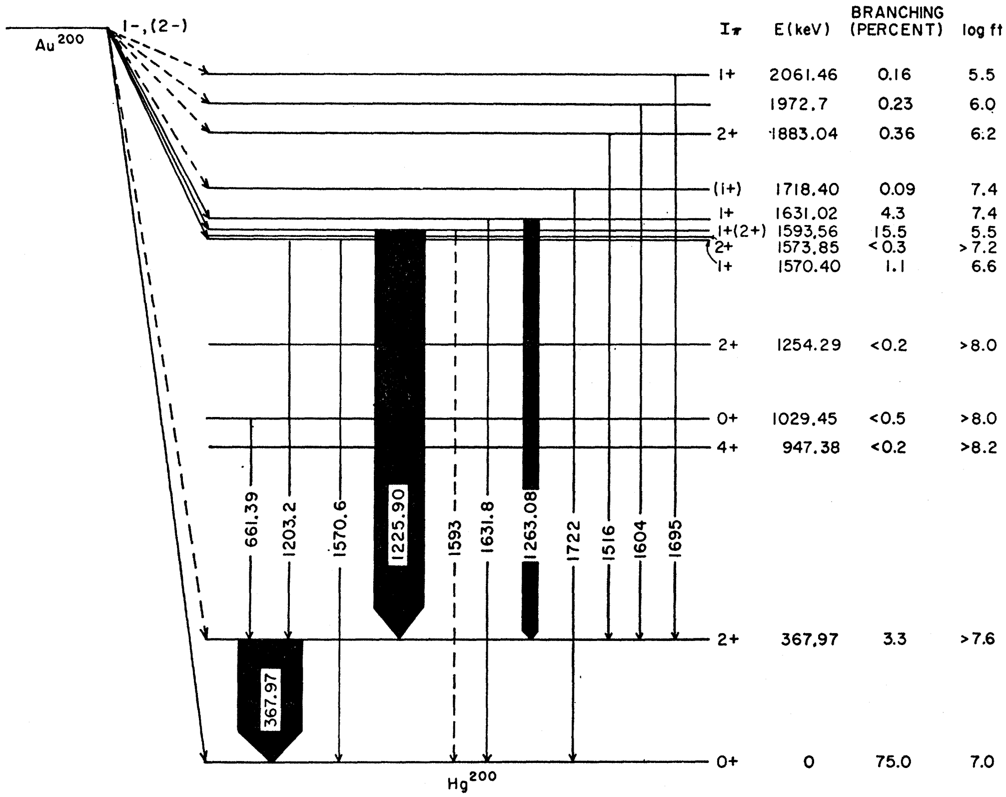

FIG. 1. γ transitions of Hg^{200} observed in the decay of Au^{200}. The level energies and certain of the transition energies shown are those obtained from the more precise results of studies of the $Hg^{199}(n,\gamma)Hg^{200}$ reaction (Ref. 5). Log*ft* values for the decay of Au^{200} to various levels of Hg^{200} have been obtained for the β-decay branching ratios shown with the use of the nomogram of Wapstra, Nijgh, and Van Lieshout (Ref. 14) and a disintegration energy of 2.20 MeV.

these two transitions, but not the 1206.8-keV transition from the level at 1573.85 keV, appear. The present results give a limit of 0.3% on the population of the 1573.85-keV level in the decay of Au^{200}.

Both the ground-state transition from the 1593.56-keV level and the intense 1225.90-keV transition to the first excited state, previously observed in the decay of Tl^{200},[4] were observed in the present work. However, since the full energy peak of the 1593-keV γ ray is superimposed on the double-escape peak (1592 keV) of a 2614-keV background line in the spectrum obtained with the Ge(Li) detector, only an approximate value for the branching ratio of the two transitions could be obtained.

The existence of a ground-state transition from the 1631.02-keV level, proposed in the neutron capture work,[5] was confirmed.

The ground-state transition from the 1718.40-keV level and the transitions from the 1883.04- and 2061.46-keV levels to the first excited state were already established in earlier work on the decay of Tl^{200}[4] and the $Hg^{199}(n,\gamma)Hg^{200}$ reaction.[8,13]

The 1604-keV transition was observed by Sakai *et al.*[4] in the decay of Tl^{200}, and the 1972.7-keV level was proposed on the basis of this and other transitions to the ground state and 1029.45- and 1254.29-keV levels. A weak 126.7-keV transition observed in the neutron capture work[8] may be placed between the 1972.7-keV level and a level at 1846.0 keV. There is thus strong evidence for the existence of the 1972.7-keV level and the placement of the 1604-keV transition between this level and the first excited state.

The very weak transitions with energies 1149, 1494, and 1507 keV, which have not been fitted into the decay scheme, probably also populate the 368-keV state. If so, the 1149-keV transition, which may be identical with the 1147.3-keV transition observed in the neutron capture work, would depopulate a state at 1515 keV. The observed 1516-keV transition might, therefore, partially originate from this state.

The β feeding of the levels is obtained on the basis of the relative γ intensities from Table I, the level scheme of Hg^{200} as shown in Fig. 1, and the result of Roy and Roy[2] that 75% of the β branches lead to the ground state. The log*ft* values are calculated from the nomogram of Wapstra, Nijgh, and Van Lieshout[14] and a disintegration energy[3] of 2.20±0.10 MeV. The errors

[13] L. V. Groshev, A. M. Demidov, V. A. Ivanov, V. N. Lutsenko, and V. I. Pelekhov, Bull. Acad. Sci. USSR, Ser. Phys. **27**, 1353 (1963).

[14] A. H. Wapstra, G. J. Nijgh, and R. Van Lieshout, in *Nuclear Spectroscopy Tables* (North-Holland Publishing Co., Amsterdam 1959).

associated with the log*ft* values increase from ~0.3 for the low-lying levels to ~0.8 for the states around 2 MeV, chiefly because of the uncertainty of the disintegration energy.

V. DISCUSSION

Several conclusions may be drawn from the log*ft* values for the decay of Au^{200} to various states of Hg^{200}.

The log*ft* value 7.0 for the β branch to the ground state of Hg^{200} implies spin and parity 0− or 1− for the ground state of Au^{200}. However, the log*ft* value (6.2) of the β branch to the level at 1883 keV, combined with the angular-correlation result I (1883-keV state) = (2,3,4) obtained by Sakai *et al.*,[4] excludes the 0− possibility. Thus Au^{200} must be 1−, with the 1883-keV state being 2+. Sakai *et al.* had previously assigned the 1883-keV state as 3+. The log*ft* values for the β feeding of the 368-, 1029-, and 1254-keV states in Hg^{200} are >7.6, >8.0, and >8.0, respectively. This result would suggest that the β decay to one- and two-phonon states is hindered in comparison with that to the zero-phonon level. Such a hindrance of β decay to higher phonon members would then make irrelevant the argument that the weakness or absence of a β branch to the 368-keV 2+ state favors 0− spin and parity for Au^{200}. Spin 1 for Au^{200} would indicate a reversal of the trend of the spins of the other odd-odd Au isotopes, in which the lighter isotopes $Au^{190,192,194}$ apparently are 1− and the heavier isotopes, $Au^{196,198}$, are 2−.

The log*ft* value for β population of the 1593-keV state is 5.5, which is 1 or 2 units less than those found for the neighboring levels. A log*ft* value of 5.5 is obtained also for the 2061-keV state. This level and the 1593-keV state decay via intense transitions to the first excited state, while the transitions to the ground state are very weak. For the 2061-keV state, the data of Groshev *et al.*[13] give an upper limit for the ground-state transition of 1.7% of the intensity of the transition to the 368-keV level. The corresponding limit for the 1593-keV ground-state transition is 0.5%. The neutron capture results are compatible with either 1+ or 2+ spin and parity for the 1593-keV level. The direct feeding of the state from the compound system formed through neutron capture slightly favors 1+. Sakai *et al.*[4] have assigned spin and parity 1+ to the 1593-keV level, which would imply multipolarity $M1$ for the 1593-keV transition. They give "$E2+M1$, large δ" for the multipolarity of the 1225-keV transition to the 368-keV state. These results[4] would therefore imply that the 1593-keV level, and probably also the 2061-keV level, are each depopulated by a highly hindered $M1$ transition. We note that Groshev *et al.*[13] assign $M1$ multipolarity to the 1225-keV transition.

Although the present experiment has aided in resolving several questions regarding the depopulation of the levels at 1593 and 1631 keV and suggests spin and parity 2+ for the 1883-keV level and 1− for the ground state of Au^{200}, several other questions remain unanswered, particularly the spin of the 1593-keV state of Hg^{200}, and the multipolarity of the 1225-keV transition. A careful study of the decay of Tl^{200} might help to clear up these questions. The investigation of these points by means of Au^{200} decay-scheme spectroscopy seems more difficult. A direct measurement of the spin of Au^{200} would be of interest.

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