Level Structure of Au^{199} from Decay of Pt^{199}

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The energy levels of Au^{199} are investigated from the decay of 30-min Pt^{199}. The high-resolution gamma spectra obtained from a Ge(Li) detector have revealed three new gamma transitions of energy 187, 469, and 497 keV. A new energy level at 324 keV has been suggested from the coincidence measurements, carried out with NaI(Tl) and Ge(Li) detectors. The possibility of an $11/2^-$ isomeric state expected in this odd-mass region of Au isotopes, has been indicated at 549 keV. A study of the internal-conversion-electron spectrum with a surface-barrier detector has clearly shown conversion lines corresponding to 187-, 247-, 318-, and 544-keV gamma transitions, and their K-shell conversion coefficients are obtained as 0.16 ± 0.04, 0.34 ± 0.05, 0.19 ± 0.02, and 0.047 ± 0.004, respectively. These measurements have indicated that the 187-keV transition is almost pure $E2$ in character, while the 247-, 318-, and 544-keV are mixtures of $M1$ and $E2$ in which the $E2$ component is very much enhanced. The gamma-gamma directional correlation of the 475–318-keV cascade has been found to be $W(\theta)=1+(0.082\pm0.01)\ P2(\cos\theta)+(0.042\pm0.03)\ P_4(\cos\theta)$. The half-life of the first excited state at 77 keV has been determined as 1.46 ± 0.12 nsec. Spin and parity assignments to the 77-, 318-, 324-, 544-, 736-, and 794-keV levels are based on these investigations, and the possible nature of these levels is discussed.

I. INTRODUCTION

THE level structure in odd-mass isotopes of Au has been of great interest and in recent years various investigations,[1–3] experimental and theoretical, have been carried out. The 79th proton in these isotopes moves in the $d_{3/2}$ orbit $(d_{3/2})^3$, and the lowest positive-parity excited states, according to the core-excitation model, may arise from the coupling of the odd nucleon to the 2^+ state of the core, leading to the quadruplet $\frac{1}{2}^+$, $\frac{3}{2}^+$, $\frac{5}{2}^+$, and $\frac{7}{2}^+$. Recent measurements[4] in Au^{197} have indicated the possibility of such a multiplet and there has been considerable discussion on the nature of the levels in this case. Braunstein and de-Shalit[2] and also de-Shalit[5] have interpreted the low-lying positive-parity levels of Au^{197} as mainly due to core excitation. By adjusting the coupling parameters A and B which take into account the admixture of $d_{3/2}$ and $d_{5/2}$ single-particle states in $|\frac{3}{2}\rangle$ and $|\frac{5}{2}\rangle$, respectively, they have tried to explain the observed experimental facts. On the other hand Kisslinger and Sorensen[6] have given an account of such levels by treating them in terms of two basic excitations, quasiparticles and phonons.

In the present work the energy levels of Au^{199} are studied from the decay of 30-min Pt^{199}. There existed several discrepancies[7] in the level scheme of Au^{199}, which were partially removed in our earlier work,[8] where these levels were correctly established by carrying out extensive beta-gamma and gamma-gamma coincidence measurements along with the study of singles and total-absorption gamma spectra, utilizing scintillation techniques. In order to get more information about the nature of the excited states, further work has been carried out by using a Ge(Li) detector and a surface-barrier detector. The high-resolution gamma spectra have revealed certain new facts. The K-shell conversion coefficients and K/L ratios for some transitions are obtained from the beta spectra taken on the surface-barrier detector. The half-life of the first excited state of Au^{199} has been measured. The directional correlation measurement for one gamma-gamma cascade is carried out. From all these measurements the nature of the excited states of Au^{199} is ascertained to some extent, and it has been compared with that of Au^{197}.

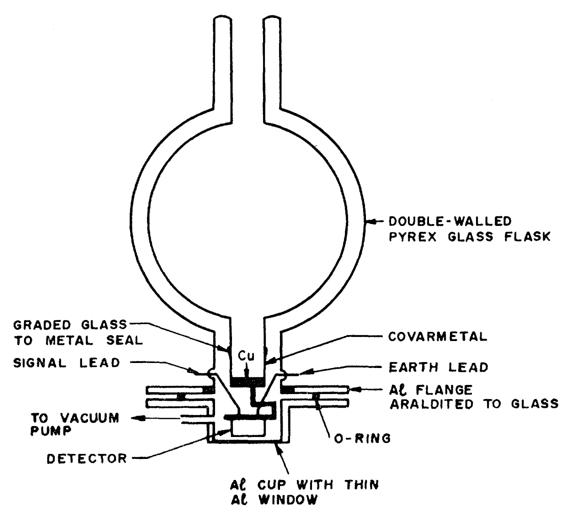

FIG. 1. A schematic diagram of the arrangement for the use of a Ge(Li) detector.

[1] *Nuclear Data Sheets* compiled by K. Way *et al.* (Printing and Publishing Office, National Academy of Sciences–National Research Council, Washington 25, D. C.) NRC, 61-3-98, 61-4-93, 5-1-17, 5-3-55.
[2] A. Braunstein and A. de-Shalit, Phys. Letters **1**, 264 (1962).
[3] J. Jastrzebski, Phys. Letters **3**, 289 (1963).
[4] A. J. Haverfield, H. T. Easterday, and J. M. Hollander, Nucl. Phys. **64**, 379 (1965).
[5] A. de-Shalit, Phys. Letters **15**, 170 (1965).
[6] L. S. Kisslinger and R. A. Sorensen, Rev. Mod. Phys. **35**, 853 (1963).
[7] J. M. Le-Blanc, J. M. Cork, and S. B. Burson, Phys. Rev. **104**, 1670 (1956).
[8] M. C. Joshi, B. V. Thosar, and K. G. Prasad, Nucl. Phys. **52**, 301 (1964).

II. EXPERIMENTAL DETAILS AND ANALYSIS

A. Source Preparation

The enriched sample of Pt^{199} (60.5%) in metallic form was obtained from the Oak Ridge National Laboratory. The sources of Pt^{199} were produced by irradiating these enriched samples in the Apsara Reactor at Trombay for a period of 30 min with a flux of 3×10^{12} neutrons/cm^2 sec. For the study of gamma-ray spectra the irradiated sample was placed on a Perspex strip, while for directional correlation measurements and conversion-line spectra, the irradiated sample was first dissolved in aqua regia and then taken in a thin-walled glass tube in liquid form, or deposited on a thin Mylar film (500 μg/cm^2), respectively. Because of the short time of irradiation, the contribution from other isotopes of Pt was very small.

B. Measurements of Gamma Spectra

The gamma spectra of Pt^{199} was studied on a lithium-drifted germanium detector of 2-mm depletion depth. A convenient arrangement (Fig. 1) for cooling the detector was made at the bottom of a glass Dewar.

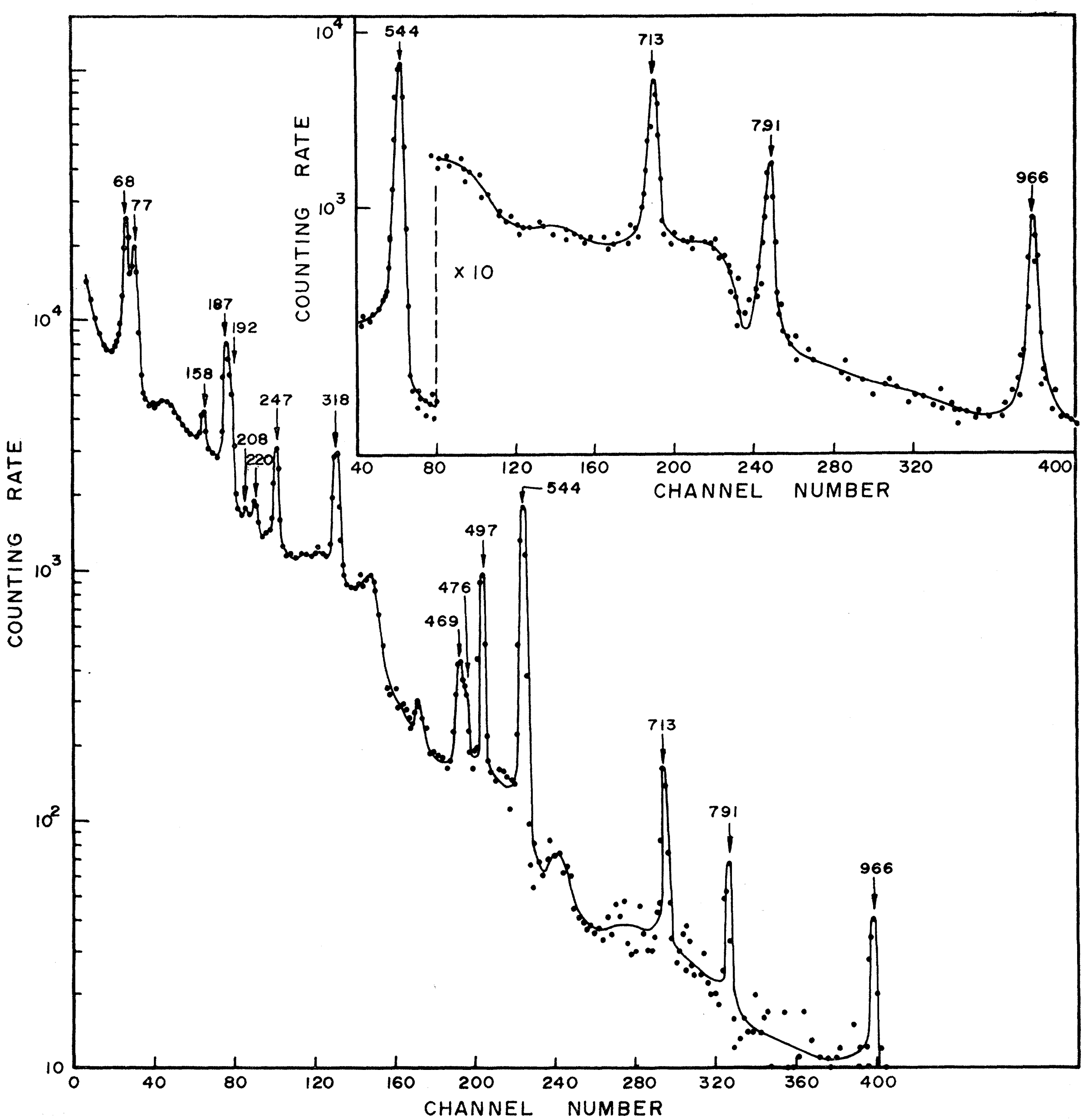

FIG. 2. The gamma-ray spectrum of 30-min Pt^{199}. In the inset is shown the high-energy part of the gamma spectrum with better statistics. The gamma rays of energies 644, 665, 836 and 889 keV as given in Ref. 17 are not observed.

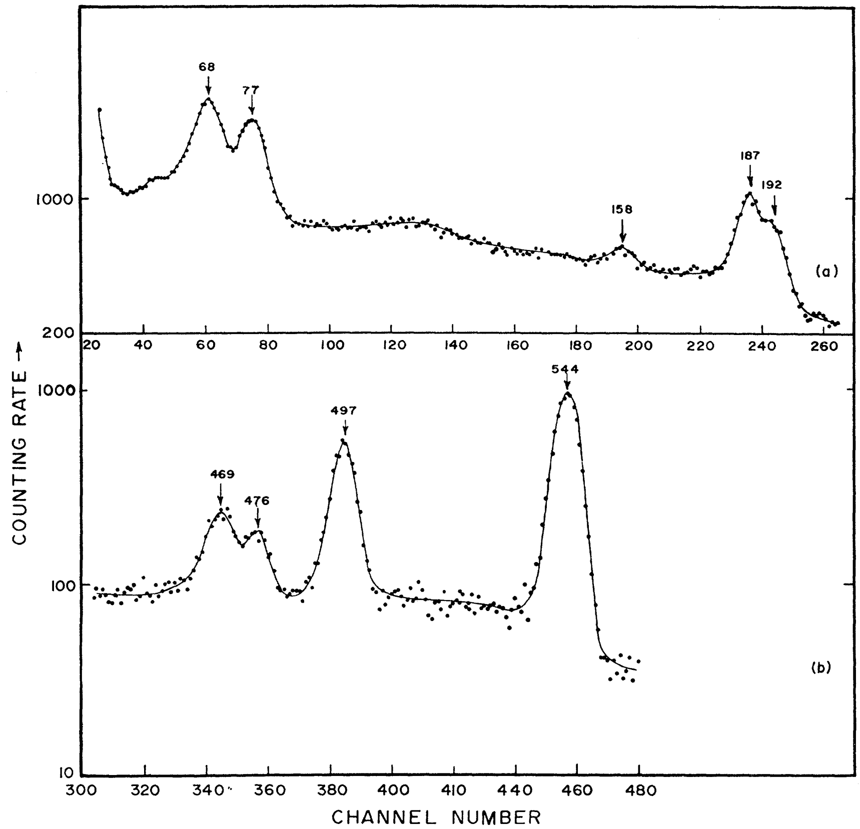

FIG. 3. The expanded gamma spectra of Pt^{199} in the energy region (a) 50–200 keV, (b) 400–550 keV, as obtained by using a biased amplifier.

In this arrangement a Kovar metal cylinder of about 1.5 in. diameter was joined to the lower part of the inner vessel of the glass Dewar with the help of a graded glass seal. The other end of the Kovar cylinder was closed with a $\frac{1}{4}$-in. thick copper disc by soft-soldering it there, and a suitable copper holder for the detector was welded to this disc. The detector in the copper holder was surrounded with a thin-window ($\frac{1}{32}$-in.) aluminum cup which was attached to the bottom of the outer vessel of the Dewar. The whole arrangement was evacuated and the detector was kept at liquid-air temperature. In this arrangement the source could be placed at a minimum distance of 1.2 cm from the detector. The pulses from the detector were amplified in an ORTEC 103–203 preamplifier-amplifier system and the gamma spectra were scanned on a 512-channel analyzer. The resolution of this detector was 6-keV full width at half-maximum (FWHM) for the 661-keV transition in Ba^{137}. The complete gamma-ray spectrum obtained from the decay of Pt^{199} is shown in Fig. 2, where the gamma rays extend from 77 to 966 keV. The 450- to 550-keV region in this spectrum is quite complex and there exist four gamma rays of energy 469, 476, 497, and 544 keV. In the earlier measurements[8] only two gamma rays of energy 475 and 544 keV were indicated in this region. On the low-energy side two close gamma rays of energy 187 and 192 keV are indicated. These two regions are more clear in Fig. 3 where the spectra are recorded after expanding the desired energy region by using a biased amplifier. The decay of all these gamma rays has been followed for four half-lives and they have been observed to follow a half-life of 30 min. The gamma ray at 220 keV also seems to follow a half-life of 30 min. But this could not be ascertained exactly because the transition is very weak. The small peaks at 158 and 208 keV (Fig. 2) are due to the decay of $Au^{199} \rightarrow Hg^{199}$. Another peak at 412 keV belongs to $Au^{198} \rightarrow Hg^{198}$.

In order to estimate the relative intensity of various gamma transitions in the decay of Pt^{199}, the relative efficiency of the Ge(Li) detector was first determined. For this purpose the gamma spectrum of $Tb^{160} \rightarrow Dy^{160}$ was recorded in the same geometry as that for $Pt^{199} \rightarrow Au^{199}$. The relative intensities of the gamma rays obtained in the decay of Tb^{160} are well known[9] from previous measurements and their energies extend from 87 to 1272 keV. The total counting rate in the photopeaks corresponding to different gamma rays in the spectrum of Tb^{160} was determined and the variation of relative efficiency for that geometry with respect to energy was estimated (Fig. 4). Since we are interested only in relative efficiencies, this method appears to be

[9] Reference 1, sheet No. NRC 59-5-83.

TABLE I. Relative intensities of gamma transitions in Au^{199}.

Gamma energy (keV)	Relative intensity from Ge(Li)	Relative intensity from NaI(Tl)	Gamma energy (keV)	Relative intensity from Ge(Li)	Relative intensity from NaI(Tl)
77	9 ±3		469	11.0±2	48 (469, 476, 497)
187	25 ±3	38 (187, 192)	476	8 ±1	
192	14 ±3				
			497	34 ±3	
220	2.5±0.5	...	544	100	100
247	13 ±2	16	713	10 ±1	14
			791	8 ±1	10
318	37 ±3	33			
			966	6 ±1	8

more convenient, and it yields similar results to those obtained by using different standard sources of known strengths. The attenuation due to the absorption in the thin window of the aluminum cup and the stainless-steel cover of the detector is automatically taken into account. Using the relative efficiencies obtained from Fig. 4, the relative intensities of all the gamma transitions in Au^{199} have been determined and are given in Table I. For the sake of comparison this table also includes the intensities obtained from a NaI(Tl) crystal from our earlier measurements.[8]

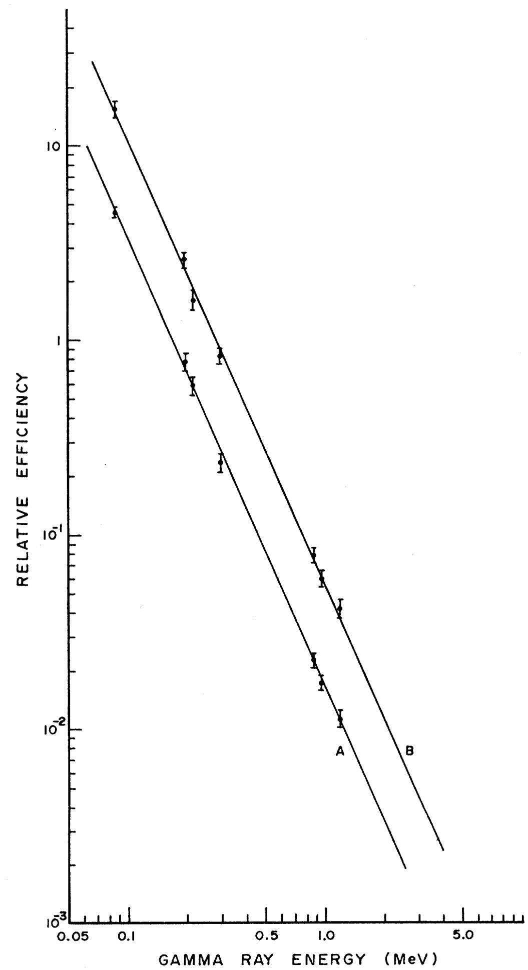

FIG. 4. The relative-efficiency–versus–energy curve for the Ge(Li) detector. Here the Tb^{160} source, in which the intensities of different gamma rays are well known, was placed at a distance of (A) 6 cm and (B) 2.5 cm from the detector.

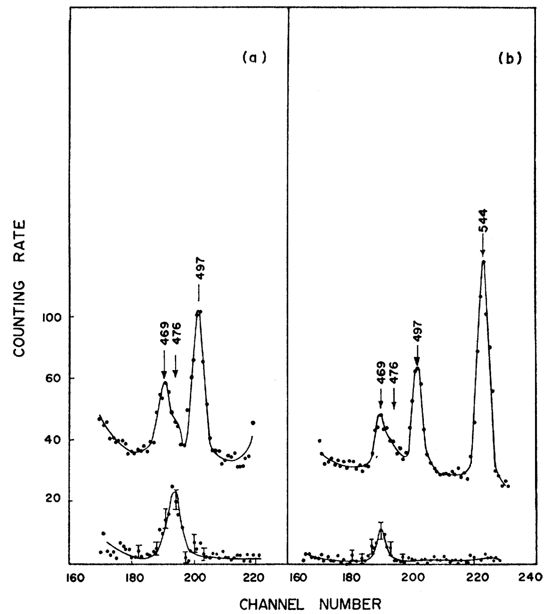

FIG. 5. The gamma-ray spectra in coincidence with (a) the 318-keV photopeak and (b) the 247-keV photopeak in the gate. Here the resolution of the Ge(Li) detector is poor, as is evident from the singles spectrum plotted above each coincidence curve, because the amplifier was used in the delay-line mode.

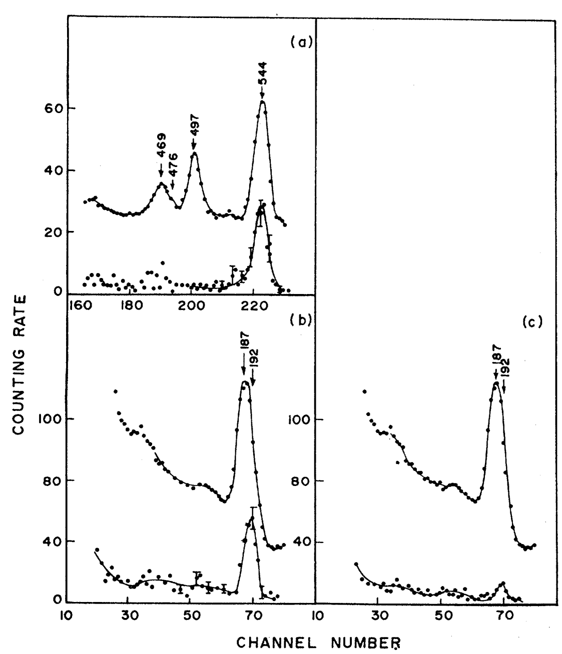

FIG. 6. The gamma-ray spectra in coincidence with (a) the 187–192-keV photopeaks, (b) the higher part of the 544-keV photopeak, and (c) the 469-keV photopeak region, in the gate.

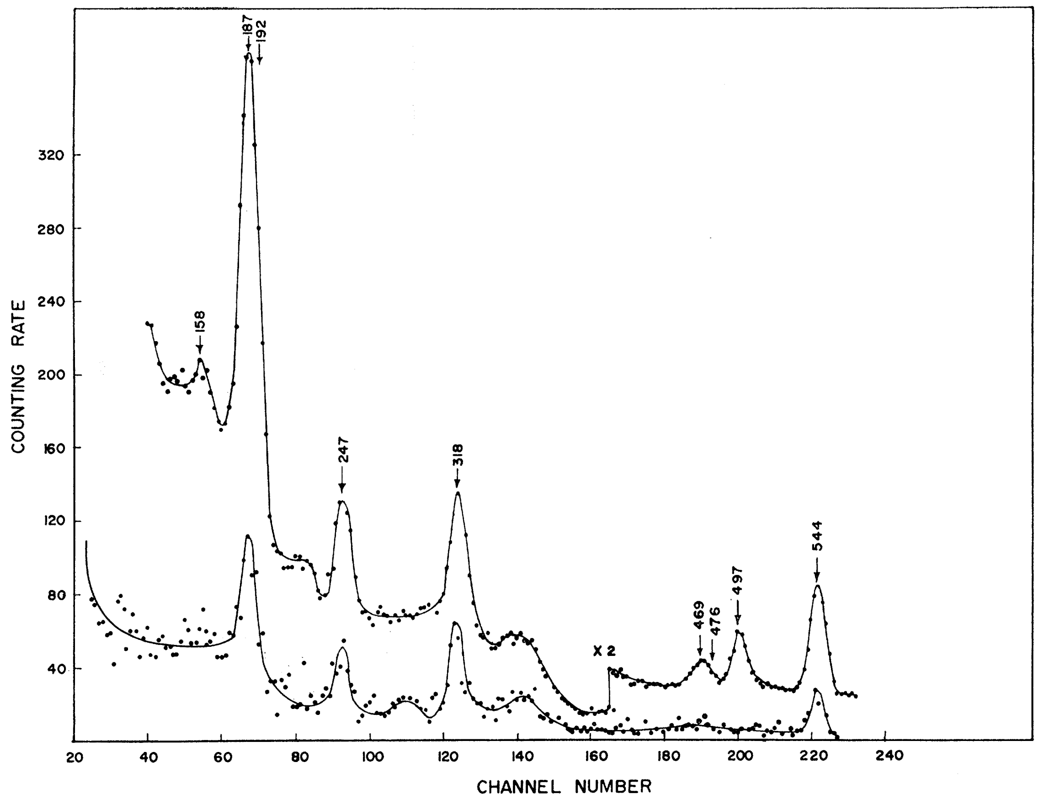

FIG. 7. The gamma-ray spectrum in coincidence with the beta rays of energy 500–600 keV.

C. The Gamma-Gamma and Beta-Gamma Coincidence Measurements

The cascade relationships of the new gamma rays observed in the high-resolution spectrum have been established in the level scheme by carrying out gamma-gamma coincidence measurements. In these measurements a 3 in.×3 in. NaI(Tl) crystal was placed facing the Ge(Li) detector. The source was placed in between the two detectors and a suitable anti-Compton shield was used to prevent spurious coincidences due to Compton scattering. The coincidence arrangement was a crossover pickoff type with a resolving time of 0.25 μsec. The gamma spectra in the Ge(Li) detector were thus observed in coincidence with the different gamma rays detected in a 3 in.×3 in. NaI(Tl) crystal. These spectra were recorded on a multichannel analyzer. As the detection efficiency in the Ge(Li) detector is very small, several coincidence runs were necessary with freshly irradiated samples for each cascade to get good statistics. In these measurements it has been clearly established that the 469- and the 476-keV gamma rays are in coincidence with the 247- and the 318-keV transitions, respectively (Fig. 5). The 544-keV gamma ray is in coincidence with the 192-keV transition (Fig. 6). The gate has been gradually shifted from the lower part of the 469-keV photopeak to the end of 544-keV photopeak, and it has been observed that the 497-keV transition is not in coincidence with any other gamma ray. Similarly the 187-keV gamma ray does not appear to be in coincidence with any other gamma transition.

The coincidence measurements were further extended to record the various gamma rays in coincidence with the beta rays of energy 500–600 keV (Fig. 7). In this measurement the coincidence arrangement was similar to that described above except that the NaI(Tl) crystal was replaced by an anthracene detector (1 cm thick×2.5-cm diam.). It is clear from this beta-gamma coincidence spectrum that the 497-keV gamma tansition is not in coincidence with the beta rays. The width of the coincident peak (Fig. 7) in the region of 187–192 keV indicates that the 187-keV gamma ray may be in coincidence with the beta rays of energy ∼500 keV.

D. Directional Correlation Measurements

The gamma-gamma directional correlation measurement in Au^{199} has been carried out for the 476–318-keV cascade. Since the half-life of $Pt^{199} \rightarrow Au^{199}$ is only 30 min, a special arrangement was used for this purpose. In this arrangement three detectors, consisting of 2-in. diam.×2-in. thick NaI(Tl) crystals coupled to RCA 6810A photomultipliers, were utilized. Out of these three detectors, two were kept fixed at right angles to each other while the third one was movable and could be brought into any suitable position. The coincidence arrangement with a resolving time $2\tau=50$ nsec was set up in two channels in such a way that the pulses from the two fixed counters could be observed in coincidence with the third one. The detectors were aligned in the usual way and the source was properly centered within an accuracy of 1% while at a distance of 5.5 cm from the detectors.

In this three-detector system, where the coincidence data at two angles can be collected simultaneously, the 476–318-keV coincidence and singles counts were collected in three positions of the movable counter every time for 5 min. By cross-adding the singles and coincidence counts thus obtained in a single set of three observations, we were able to collect double the number of counts obtained in a two-detector system, at each of the three angles 90°, 135°, and 180°. By taking a large number of such sets for the above cascade, a total of 30 000 counts at three angles were collected. The details of this three-detector system and cross-adding method have been described elsewhere.[10] As explained in Ref. 10, it is not necessary to apply the decay correction in this method, so that this method is more advantageous for short-lived activities with active daughter products as is the case in Pt^{199}. The other uncertainties due to small shifts in photopeaks and window widths are also reduced considerably.

Each set of observations comprising the singles and coincidence data at 90°, 135°, and 180° for the 476–318-keV cascade was individually analyzed in the usual way by normalizing the coincidence counts to the singles counting rate and then calculating the anisotropy at 135° (A_{135}) and at 180° (A_{180}). In the end, properly weighted means of A_{135} and A_{180} were found for all sets of observations. The coefficients A_2 and A_4, defined by the equation $W(\theta)=1+A_2P_2(\cos\theta)+A_4P_4(\cos\theta)$, were calculated. Here the solid-angle attenuation corrections were made according to Rivers and Stanford.[11] The coefficients thus obtained are as follows:

$$A_2=0.082\pm0.01\,,\quad A_4=0.042\pm0.031\,.$$

E. Lifetime Measurements

The half-life of the first excited state at 77 keV in Au^{199} has been measured by using the modified Green-Bell-type[12] 6BN6 time-to-pulse-height converter. For this purpose a suitable gamma-gamma cascade (713–77 keV) was selected so as to avoid the contribution of any other transition in the coincidence counting. The delayed coincidences between the 77- and the 713-keV gamma rays were observed on a multichannel analyzer. The 77- and the 713-keV gamma rays were detected in a 1-in. thick×1.5-in. diam and a 2-in. thick×2-in. diam NaI(Tl) crystals, respectively. In this arrangement the slope of the prompt curve as obtained by using the annihilation photons from a Na^{22} source with the one side gate fixed at the 77-keV energy region was 0.9 nsec.

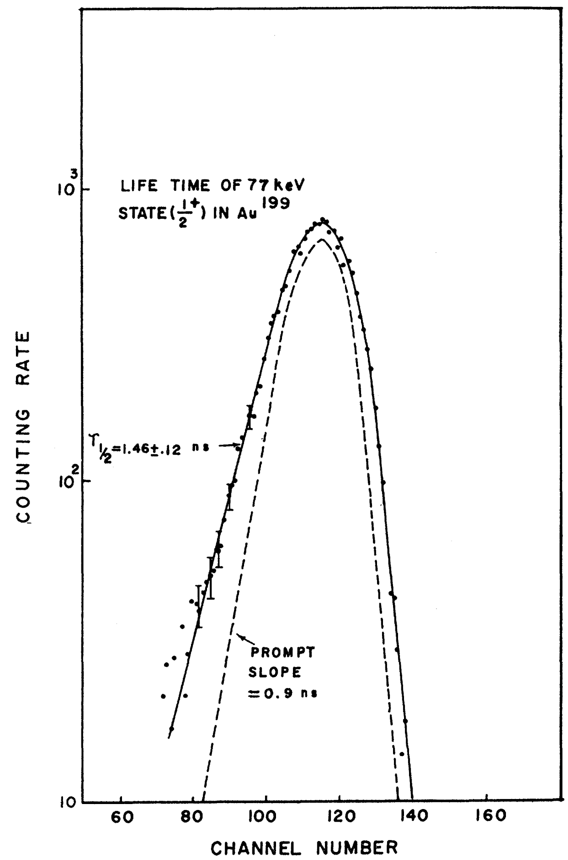

FIG. 8. The time-to-pulse-height conversion spectrum for the 713–77-keV cascade. The prompt coincidence curve is shown by the dashed line.

The time spectra in Au^{199} for the 77-keV excited state were recorded in several runs on the multichannel analyzer by irradiating fresh samples of Pt^{198} every time. Frequent checks were made for any shift in the prompt peak by repeating the prompt measurement with a Na^{22} source under almost similar conditions after every hour. The counts collected in each channel of the above time-to-pulse-height conversion (TPC) spectra for the 713–77-keV cascade, obtained in different runs, were added, and the final curve thus obtained is given in Fig. 8. It is evident from this TPC curve that the half-life of the 77-keV excited state is 1.46±0.12 nsec.

F. Internal-Conversion Coefficient Measurements

The conversion-line spectrum of Au^{199} has been studied on a *p-n*–type surface-barrier detector with a depletion-layer thickness of 500 μ. This thickness is sufficient to absorb electrons of energy 400 keV. The detector was used at liquid-air temperature in a similar

[10] V. R. Pandharipande, K. G. Prasad, R. M. Singru, and R. P. Sharma, Phys. Rev. **143**, 740 (1966).
[11] A. L. Stanford, Jr., and W. K. Rivers, Jr., Rev. Sci. Instr. **30**, 719 (1959).
[12] R. E. Green and R. E. Bell, Nucl. Instr. Methods, **3**, 127 1958).

TABLE II. The K-shell internal-conversion coefficients and K/L ratios. The theoretical values as obtained from Rose's[a] table are given for comparison. The last column gives the $E2/M1$ ratio as calculated from the single-particle transition probabilities given by Moszkowski.[b] It is evident that the $E2$ component in each transition given below is very much enhanced.

E_γ (keV)	α_K experimental	α_K theoretical $M1$	$E2$	K/L (Expt)	K/L (theoretical) $M1$	$E2$	Multipolarity	$E2$ admixture %	$E2/M1$ Based on single-particle estimates
544	0.047±0.004	0.060	0.0165	6±1	6.6	3.75	$M1+E2$	29±9	0.88×10^{-3}
318	0.19 ±0.02	0.24	0.055	5±1	6.3	2.2	$M1+E2$	27±10	3×10^{-4}
247	0.34 ±0.05	0.47	0.100	4.5±1	6.2	1.47	$M1+E2$	35±10	1.8×10^{-4}
187	0.16 ±0.04	1.0	0.190	1±0.2	6.25	0.9	$E2$	100	

[a] See Ref. 14. [b] See Ref. 13.

arrangement to that described above for the Ge(Li) detector, except that the aluminum cup was replaced by an aluminum chamber with an attachment for introducing the beta source without breaking the main vacuum. Care was taken to avoid the deposition of oil vapors from the diffusion pump by using a suitable liquid-nitrogen trap. A positive bias of 300 V was applied to the detector, and the pulses from it, after being amplified by an ORTEC 103–203 preamplifier-amplifier system, were analyzed in the multichannel analyzer. The internal-conversion line spectra corresponding to the 114-keV transition in In^{114m}, the 279-keV transition in Tl^{203}, the 567-keV transition in Pb^{207}, and the 661-keV transition in Ba^{137} were used as standards, while the 346-keV isomeric transition in 86-min Pt^{197m} was used for checking purposes in our measurements. Two standard spectra, one for Tl^{203} and the other for Ba^{137}, are shown in Fig. 9. The FWHM as inferred from these standard spectra is 8 keV.

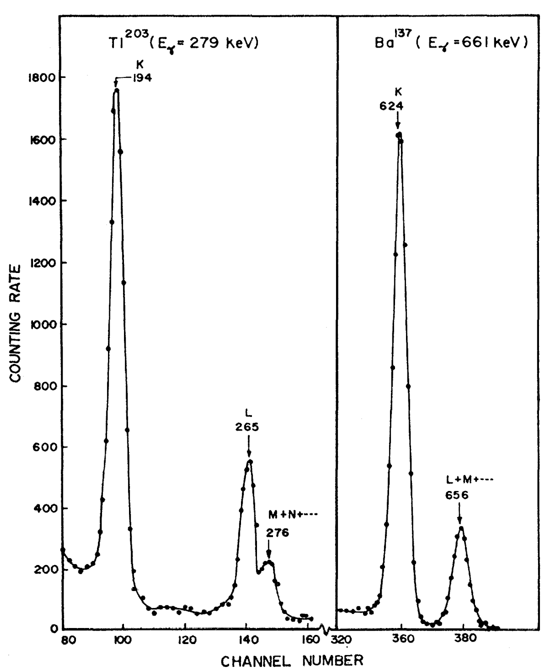

FIG. 9. The internal-conversion line spectra, recorded with a surface-barrier detector, for the 279-keV and the 661-keV gamma rays in Tl^{203} and Ba^{137}, respectively.

The internal-conversion line spectrum of Au^{199} is given in Fig. 10. In this figure the conversion lines corresponding to the 187-, 247-, 318-, and 544-keV transitions are clearly seen. The K and L lines of the 544-keV transition are quite clear and free from any other contributions, while those corresponding to the 187-, 247-, and 318-keV transitions are mixed, as indicated in Fig. 10. The intensities of these conversion lines corresponding to 187-, 247-, and 318-keV gamma rays were determined by using the conversion line shapes of monoenergetic lines in In^{114m} and Tl^{203}. The K-shell conversion coefficients for all the above transitions are determined from the following relationship:

$$\alpha_K=\frac{I_e}{I_\gamma}\frac{\eta_\gamma(E_\gamma)}{\eta_e(E_e)}\frac{\omega_\gamma}{\omega_e}.$$

In this expression I_e and I_γ are the total numbers of counts in the K-conversion line and the photopeak of the corresponding gamma ray, respectively. Since the half-life of $Pt^{199}\rightarrow Au^{199}$ is only 30 min and a thin, peak source was necessary for a conversion-line spectrum, the gamma spectrum of the beta source prepared immediately after irradiation was taken on a 3 in.×3 in. NaI(Tl) crystal before introducing the source into the aluminum chamber for taking the conversion line spectrum. In this way by determining the intensity of one gamma ray, either 318 or 544 keV (both of which appear well resolved in the scintillation spectrum), the intensities, of other gamma rays were estimated from the known relative intensities from a Ge(Li) detector. The factor $\eta_\gamma(E_\gamma)\omega_\gamma/\eta_e(E_e)\omega_e$ in the above expression represents the ratio of the product of photoefficiency and solid angle in the NaI(Tl) detector to the product of electron detection efficiency and solid angle in the surface-barrier detector. The photoefficiencies in a 3-in.×3-in. NaI(Tl) crystal were obtained from standard curves while the quantity $\omega_\gamma/\eta_e(E_e)\omega_e$ was experimentally determined from known values of internal-conversion coefficients of the 191-, 279-, 567- and 661-keV monoenergetic transitions in In^{114m}, Tl^{203}, Pb^{207}, and Ba^{137}, respectively. The gamma and conversion line spectra of these sources were taken under similar conditions to those employed for Au^{199}. It may be noted that the conversion-line energies of these standard transitions are approximately in the

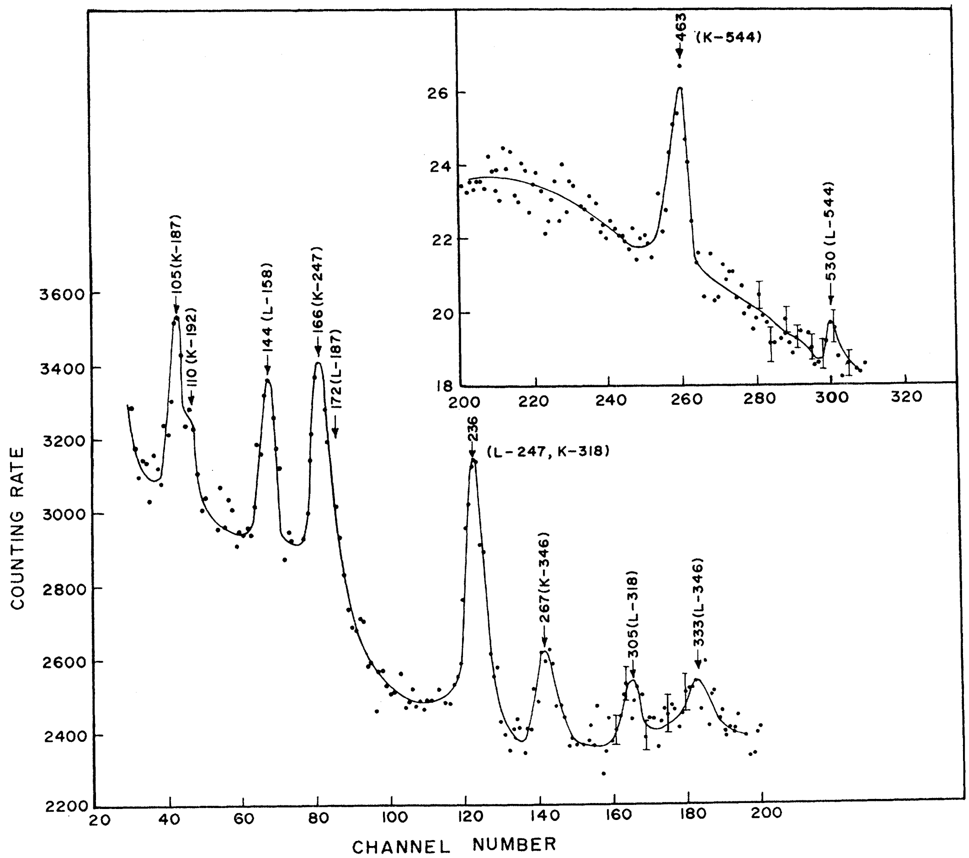

FIG. 10. The internal-conversion line spectrum of Au^{199}. The K and L conversion lines for the 544-keV gamma transition are shown in the inset. The peaks at 267- and 333-keV energy are the K and L lines for the 346-keV transition belonging to 86-min Pt^{197m}.

same energy regions as those investigated in Au^{199}. A plot of the quantity $\eta_e(E_e)\omega_e/\omega_\gamma$ against energy is given in Fig. 11. The α_K values for the 187-, 247-, 318- and 544-keV transitions are thus determined and are given in Table II.[13,14] This table also includes the K/L ratios and the percentage $E2$ and $M1$ mixture in each transition.

III. RESULTS AND DISCUSSION

The energy levels of Au^{199} are given in Fig. 12. These were established earlier,[8] except the one at 324 keV and those shown by dashed lines. The 324-keV level has been proposed as a result of the 469–247-keV gamma-gamma coincidence measurements. The levels shown by dashed lines will be discussed later in the text.

The ground state of Au^{199} is known to be $\frac{3}{2}^+$ as measured by the atomic-beam method.[15] The earlier measurements[16] regarding the energy levels of Pt^{199} have indicated that the spin and parity of its ground state is $\frac{5}{2}^-$. From the systematics of odd-mass Au isotopes[1] and the high log ft value ($\sim$8) of the beta transition to the first-excited state[8] of Au^{199}, it seems probable that the spin and parity of this state is $\frac{1}{2}^+$. The half-life of this state at 77 keV as determined above is 1.4±0.12 nsec. The retardation in the 77-keV $M1$ transition to the ground state indicates that the first excited state

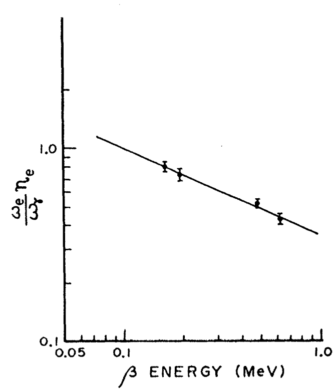

FIG. 11. A plot of $\eta_e\omega_e/\omega_\gamma$ against energy. The quantity η_e represents the efficiency for "full energy" electron absorption in the surface-barrier detector.

[13] M. E. Rose, *Internal Conversion Coefficients* (North-Holland Publishing Company, Amsterdam, 1958).

[14] S. A. Moszkowski, *Alpha, Beta, and Gamma ray Spectroscopy*, edited by K. Siegbahn (North-Holland Publishing Company, Amsterdam, 1965), Chap. XV.

[15] R. L. Christensen, D. R. Hamilton, A. Lemonick, F. M. Pipkin, J. B. Reynolds, and H. H. Stroke, Phys. Rev. **101**, 1389 (1956).

[16] M. A. Wahlgren and W. W. Meinke, Phys. Rev. **115**, 191 (1959).

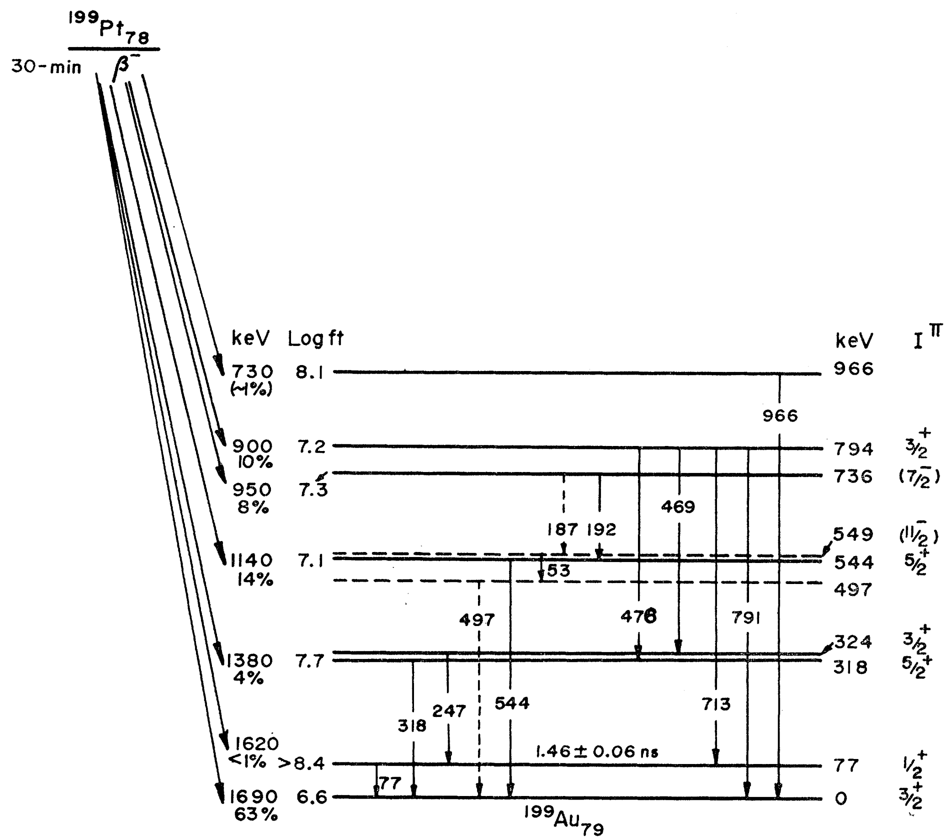

FIG. 12. Energy levels of Au^{199} as populated in the decay of 30-min Pt^{199}.

in Au^{199} may be of similar character to that in Au^{197}. In Au^{197} the first excited state has a half-life of 1.8 nsec.[1]

The analysis of the 476–318-keV gamma-gamma directional correlation results has indicated possible spins of $\frac{3}{2}$ and $\frac{5}{2}$ for the 794- and 318-keV excited states, respectively. The other possibilities are ruled out from the observed positive sign and nonzero value of the A_4 term (0.042±0.031). The analysis has further indicated the possibility of enhanced $E2$ mixture in the 318-keV transition. Actually the measurement of the internal-conversion coefficient α_K along with the K/L ratio for the 318-keV transition (Table II) has indicated a (27±10)% $E2$ mixture in this transition.

The 324-keV excited state decays mainly by the emission of a 247-keV gamma ray to the $\frac{1}{2}^+$ first excited state at 77 keV. The α_K measurement for the 247-keV transition has shown that it is a mixture of $M1$ and $E2$. It thus seems more probable that the spin and parity of the 324-keV level is $\frac{3}{2}^+$, because a $\frac{5}{2}^+$ assignment here will make the 247-keV transition a pure $E2$ one. It is important to note here that this excited state at 324 keV does not decay to the ground state directly.

In a similar way, as mentioned in Table II, the 544-keV gamma ray is seen to be a mixture of $M1$ and $E2$. The excited state at 544 keV, which decays to the $\frac{3}{2}^+$ ground state, will therefore have the probable spin and parity $\frac{3}{2}^+$ or $\frac{5}{2}^+$. A large $M1$ admixture (28%) in the 544-keV transition has ruled out a $\frac{7}{2}^+$ assignment to this state.

The 544-keV excited state is populated by the beta decay of Pt^{199}, and the log ft value corresponds to a first-forbidden character of this transition. It is also populated by the 192-keV transition from the 736-keV excited state. The small internal conversion of the 192-keV gamma ray, as evident from Fig. 10, indicates that it might be an $E1$ transition.

In Fig. 12 the 736-keV excited state is also shown to decay to the $\frac{3}{2}^+$ ground state via the 549- and 497-keV levels by the emission of the cascade 187–53–497 keV. It has been mentioned above that the 497-keV transition is not observed in any coincidence measurements. Similarly 187 keV has not been observed in gamma-gamma coincidence measurements. However, the decay of these two gamma rays has a half-life of 30 min, so they appear to belong to the decay of Pt^{199}. The gamma ray of energy 53 keV mentioned in the cascade 187–53–497 keV has not been observed in our investigations. Black[17] has recently reported a highly converted 55-keV transition from his measurements of the decay of Pt^{199} with a permanent-magnet spectrograph. If we now examine the energy levels of Au^{193}, Au^{195}, and Au^{197} we

[17] W. W. Black, Bull. Am. Phys. Soc. 10, 481 (1965).

will find an $11/2^-$ level, corresponding to the $h_{11/2}$ shell-model state for the 79th proton, existing in all these odd-mass isotopes. A similar level might also exist in Au^{199}. In such a case an $11/2^-$ level at 549 keV in Au^{199} might be populated by a 187-keV transition from the 736-keV state, which in turn decays by a highly converted transition of energy 53 keV and the abovementioned 187–53–497-keV cascade might exist.

In our earlier work,[8] from the large observed intensity of the 475-keV gamma ray in the scintillation spectrum, the $11/2^-$ level was proposed at 475-keV energy, directly decaying to the $\frac{3}{2}^+$ ground state. Since no conversion line (Fig. 10) corresponding to an $M4$ transition $(11/2^- \rightarrow \frac{3}{2}^+)$ of energy 475 keV has been observed, this inference regarding the isomeric state at 475-keV energy is not tenable.

The K-shell conversion coefficient of the 187-keV transition as given in Table II indicates a pure $E2$ character of this transition. The spin and parity of the 736-keV excited state may therefore be $\frac{7}{2}^-$. This assignment restricts the spin and parity of 544-keV level to $\frac{5}{2}^+$, because only then can the weak conversion of the 192-keV gamma ray and consequently its probable $E1$ character be explained.

A careful study of the nature of the various transitions as described above will show that the level structure in Au^{199} is quite complex. It is difficult to point out in this case all the members of a core quadruplet arising from the coupling of the $d_{3/2}$ proton with the first 2^+ vibrational state of the even-even core. In Au^{199} the $\frac{1}{2}^+$ first excited state at 77 keV is of similar character to that in Au^{197} and may be the lowest state of the core multiplet. The next excited state, i.e. the $\frac{5}{2}^+$ at 318 keV, may also be the member of this multiplet, since it decays to the ground state by a transition having an enhanced (27%) $E2$ component. Such is not the case with the $\frac{3}{2}^+$ level at 324 keV. This state does not decay to the ground state but to the $\frac{1}{2}^+$ first excited state at 77 keV. The enhanced $E2$ component (35%) in the 247-keV transition suggests that the 324-keV level may have a large admixture from the coupling of the odd particle in the $\frac{1}{2}^+$ state to the first phonon. The second $\frac{5}{2}^+$ state at 544 keV could arise in two ways, firstly by the coupling of the $d_{3/2}$ proton with the second phonon, and secondly as a single-particle state with an admixture from the first $\frac{5}{2}^+$ excited state. The former possibility is ruled out by the absence of the decay of the 544-keV excited state to the first-phonon coupled states. Thus the second possibility appears to be more favorable, especially as it is also supported by the large $M1$ admixture in the 544-keV ground-state transition.

The negative-parity state at 736 keV having a spin $\frac{7}{2}$ could arise from the coupling of the 79th proton in the $h_{11/2}$ orbital with the 2^+ phonon. This is supported by the observed pure $E2$ character of the 187-keV transition.

The position of the weak 220-keV transition, which seems to have a 30-min half-life, has not been indicated in the present level scheme of Au^{199}, because it was difficult to observe it in coincidence measurements.

In conclusion it can be said that de-Shalit's core-excitation model, as applied in Au^{197}, does not seem to describe the energy levels in Au^{199} very well. The low-lying positive-parity excited states, as described above, contain considerable admixtures from various single-particle and phonon states. Such admixtures have been taken into account in a generalized theoretical treatment of the energy levels of spherical nuclei by Kisslinger and Sorensen.[6] Here again the agreement between theory and experiment is not very good. A more rigorous calculation is necessary to account for the present level structure of Au^{199}.

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